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SASKATCHEWAN WATER CORPORATION

Managing a Vital Resource

IRRIGATION WATER QUALITY - SOIL COMPATIBILITY

GUIDELINES FOR IRRIGATION IN SASKATCHEWAN

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IRRIGATION WATER QUALITY - SOIL COMPATIBILITY GUIDELINES

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WATER QUALITY-SOIL COMPATIBILITY

GUIDELINES FOR SASKATCHEWAN

I. INTRODUCTION

One of the major problems that has plagued committees in assessing and setting water quality criteria for irrigation is the variety and variability of factors and interactions that play a role in irrigation. Salinity of irrigation water is often considered the most important factor. In addition, many other factors including the chemical composition of the water, physical make-up of the soil, interaction of the irrigation water with the soil chemistry, salt tolerance of the crop being irrigated, leaching fraction, climate of the area, type of irrigation system, and level of management, all play important roles. The presence of excessive amounts of specific ions, toxic compounds or elements, microorganisms, and pesticides must also be considered.

Recently, the matter has been further complicated by "new" sources of water, i.e. water sources which have previously not been utilized extensively for irrigation in Saskatchewan. The use of agricultural land for irrigation with secondary lagoon effluent waters is on the increase. Small and fairly isolated irrigation tracts utilizing groundwater are being tested. The disposal of some industrial waters by irrigation is being considered.

These sources are relatively new to agricultural irrigation in Western Canada. Their presence has complicated the assessment of water quality criteria for irrigation and has caused some changes in our thinking regarding irrigation standards. Researchers have been, and continue to be, in the throes of re-examining and re-evaluating water quality objectives. New knowledge is being gained and it is expected that in the next decade, major advances in our understanding and rationale for irrigation water quality and soil-suitability will be forthcoming.

There is no set of standards or guidelines available for Saskatchewan that can be utilized for irrigation investigations (surface water, groundwater, and effluent water) where both the water quality and soil compatibility aspects for irrigation have been considered together. Saskatchewan Environment (1983) does have guidelines for surface water quality and these are being updated based on the 1987 Canadian Water Quality Guidelines. Often water quality standards for irrigation (agriculture) have been developed based on salt content (EC or TDS), sodium adsorption ratio (SAR), boron or other constituents assuming a well drained soil. Similarily, soils or land classification criteria for irrigation have often been developed assuming the use of good quality water. In some recent investigations there has been an effort to consider both water quality and soil properties to determine an overall suitability for irrigation. To some extent the compatibility of soil to certain types of water quality becomes a "site specific" problem, but even in these situations there are few guidelines to follow.

The compatibility between soil and water quality becomes strained under situations of increasing salt content of the irrigation water and where the soil has poor drainage characteristics. Effluent irrigation often involves the application of saltier waters where a larger leaching fraction is required to prevent excessive salt build-up. In these situations soil drainage criteria could become a limiting factor and warrant careful evaluation before approval and implementation of irrigation. From an environmental standpoint, even though the effluent quality may not be ideal for the soils at a particular site, it may still be the preferred disposal option for the overall protection of the environment.

In this context disposal, not irrigation, is the operative process.

II. OBJECTIVE

The primary objective of this study is to provide a comprehensive set of soil and water quality guidelines for irrigation (in Saskatchewan) including the use of surface waters, groundwaters, and wastewaters on agricultural lands.

Although the framework of the study will stay within generally accepted criteria for water quality and soil-land suitability classifications, special attention will be focused on refining recommendations for application of poorer quality water to Saskatchewan soils.

The philosophical framework for the development of these guidelines can be summarized as follows:

"Saskatchewan soils are a valuable agricultural resource whose productivity can often be enhanced by irrigation. While irrigation can provide the benefit of increased productivity, it can also damage the soil if the irrigation water quality is not compatible with the soil. The purpose of these guidelines is to maximize the benefits associated with irrigation with various water categories while minimizing soil degradation and preserving environmental quality. It is also the intent of these guidelines to ensure that agricultural lands benefit from irrigation and do not receive harmful quantities of undesirable elements and substances."

III. WATER SOURCES

There are three general categories of water which have potential use for irrigation on agricultural land in Saskatchewan. The three categories of water include:

A. Surface water

B. Groundwater

C. Effluent water

(1) Municipal

(2) Agricultural

(3) Industrial

Surface waters from rivers, reservoirs, sloughs, and spring-runoff (backflood) are the major sources of irrigation waters in Saskatchewan. Irrigation from groundwater is just beginning. Much of Saskatchewan's groundwater tends to be highly mineralized and not suitable for irrigation except under certain conditions. The use of effluent waters from sources such as municipal sewage treatment lagoons, livestock lagoons, or various industrial sources (canneries, milk processing and malting plants) for irrigation is becoming increasingly acceptable. Disposal of effluent by irrigation of agricultural land is sometimes considered beneficial because of the nutrient content of the water.

In Saskatchewan, there is increasing pressure for irrigation development particularly for the disposal of effluent waters as an alternative to more costly waste treatment processes. Irrigation development provides stability to crop production and utilizes water which would likely be unused otherwise. Municipalities and industries look at effluent irrigation as a relatively inexpensive waste disposal method which might provide "symbiotic" benefits to agriculture.

A. Surface Water

Most surface water sources in Saskatchewan have relatively good quality for irrigation. Tables 1a and 1b summarize some of the chemical data for a few of the river systems and reservoirs in the province.

However, there are some major lakes in Saskatchewan (Little Quill, Old Wives) south of the 54th parallel that have total dissolved solid (TDS) levels greater than 1000 mg/ℓ and many which have TDS levels greater than 10,000 mg/ℓ (Manitou, Big Quill). These waters have very limited potential for irrigation (Cameron, 1985).

Problems with irrigation water quality become more apparent in dry years on small rivers and reservoirs when flows become minimal and evaporation and groundwater discharge can concentrate the salt content of the water.

Table 1a: Average Chemical Composition of Some Saskatchewan Rivers Used For Irrigation

	EC (mS/cm)	TDS	Na	Ca	MG	K	SO4	Cℓ	HCO3	SAR
		mg/ℓ								
South Sask River Near Outlook	0.3	226	17	48	18	2	60	3	172	0.6
Swift Curr. Creek at Swift Current	0.7	457	50	66	–	7	178	7	241	1.3
Frenchman River at U.S. Border	1.0	751	119	66	53	10	373	8	255	2.7
Wood River Near Gravelbourg	1.2	689	134	61	–	13	329	9	245	3.7
Moose Jaw River at Moose Jaw	1.1	1033	208	100	21	20	360	168	305	4.4
Souris River Near Estevan	0.9	658	138	58	–	15	256	27	259	4.0
Arm River Near Bethune	1.2	1203	159	93	–	17	626	23	359	2.5
Qu'Appelle River Below Craven	1.1	1183	220	87	–	25	482	128	342	4.2
Qu'Appelle River Near Grenfell	1.3	1185	213	99	–	19	513	97	353	4.2
Assiniboine River at Kamsack	1.0	619	45	110	–	9	188	22	421	0.9
North Sask. River at No. Battleford	0.3	241	16	52	17	2	58	12	178	0.5

1. Environment Canada. 1977. Water quality data, Saskatchewan 1961-1975. Inland Waters Directorate.

Table 1b: Chemical Composition of Some Saskatchewan Reservoirs Used For Irrigation.

		EC	Na	Ca	Mg	K	SO4	Cℓ	HCO3	SAR	pH
	Date	(mS/cm)	mg/ℓ								
Eastend	June/85	0.5	35	35	30	7	71	3	—	1.0	7.9
Reservoir	Aug/85	0.4	34	15	25	3	61	5	84	1.2	9.8
Gouverneur	May/85	1.7	290	50	34	17	550	13	—	7.8	8.3
Reservoir	June/85	2.0	380	64	52	22	710	13	—	8.6	8.8
	Aug/85	2.4	400	56	52	22	740	19	440	9.3	8.8
Cadillac	May/85	2.1	430	19	18	14	650	14	—	17.0	8.3
Reservoir	June/85	2.6	570	31	26	22	800	12	—	18.3	8.2
	Aug/85	3.4	680	37	33	24	1040	19	919	19.6	8.6
Val Marie	June/85	0.8	70	64	40	13	250	5	—	1.7	8.1
Reservoir	Aug/85	1.4	139	80	76	15	490	11	318	2.7	7.4
Summercove	July/85	1.1	151	48	44	18	340	9	—	3.8	8.1
Reservoir	Aug/85	1.4	170	48	44	22	350	14	414	4.3	7.6
Lake	July/85	0.7	48	53	60	16	66	7	—	1.1	8.4
Pelletier	Aug/85	0.7	49	20	64	15	68	10	403	1.2	8.6
Thomson	July/85	1.1	146	52	32	15	370	9	—	3.9	7.8
Lake Res.	Aug/85	1.2	157	48	33	15	350	12	251	4.3	8.5

1. Irrigation Branch, Outlook, Saskatchewan - data collected during drought year of 1985.

B. Groundwater

Rutherford (1967) conducted a quality survey of Saskatchewan groundwaters and developed a chemical classification for groundwater. A summary of Rutherford's findings is presented below:

WATER TYPE	TDS (mg/ℓ)	SAMPLES	GEOLOGICAL OCCURENCE
Ca (Mg) (HCO3) 2	406-85	813	Mainly in upper drift, some in Cypress Formation as well as Ravenscrag and Judith River in presence of coal seams.
Ca (Mg) SO4	1786-2516	1173	Mainly lower glacial drift, some upper drift, Cypress Formation and sporatic in Bearpaw and Judith River.
Na2SO4	2054-3950	51	Mainly lower glacial drift Eastend, Bearpaw, Ravenscrag, Judith River and Lea Park Formations.
Na2CO3 (SO4)	2572-4910	13	Judith River, Bearpaw and Marine Shale Formations.
NaHCO3	748-1552	244	Judith River, Cypress, Ravenscrag, Eastend, Bearpaw, and Lea Park Formations.
NaCl (HCO3)	1350-4637	83	Judith River, Bearpaw, Ravenscrag, and Marine Shale Formations.

Groundwaters with better quality are found in the upper glacial drift and those with poorer quality are found in the deeper formations. Most of the aquifers suitable for pumping large volumes of water are located within the deeper strata where water quality is considered marginal for irrigation. The aquifers in the upper glacial till are generally not extensive nor as well defined as those in the underlying formations.

Recently Bachman, Cameron, Jame, and Nicholaichuk (1981) studied the feasibility of utilizing Saskatchewan groundwaters for irrigation.

They concluded that a large portion of the groundwater has marginal quality and that prolonged application could cause problems on many soil types. Gillies et al (1985) summarized the results of two experimental groundwater irrigation projects in Saskatchewan, one near Donavon, (80 km southwest of Saskatoon) pumping from the Tyner Valley Aquifer and one from near Watrous (130 km southeast of Saskatoon) pumping from the Hatfield Valley Aquifer. Both the Donavon and Watrous systems are irrigating deep coarse textured soils with groundwaters having an EC of 3.2 and 4.1 mS/cm and SAR's of 13.5 and 15.4, respectively. They have observed a salt and SAR increase in the soil, but there was no visible effect of this accumulation on crop production after five years of application.

C. Effluent Water

Utilization of effluent for irrigation on agricultural land is becoming both economically and environmentally acceptable in many areas (Enviroment Canada, 1984). In Saskatchewan, Swift Current and Moose Jaw have set up large irrigation systems to dispose of secondary effluent and other communities have followed this lead (Nicholaichuk et al, 1982; Underwood McLellan Ltd., 1978; and Wiebe, 1982).

Generally, one would expect the salt content of lagoon water to be correlated with the salt content of the source water. Chemical content of industrial effluent tends to reflect industrial processes. Typical values for salt content in industrial and municipal wastewaters around the world have been summarized and are presented in Table 1c.

In terms of total irrigation, the volume of water and the irrigated acreage from lagoon systems are relatively small in Saskatchewan. One of the major concerns with these waters has been their salt content and the compatibility of soils to handle the salt composition and salt load.

Table 1c: Typical salt contents of industrial and municipal wastewaters.

LOCATION	TDS (mg/ℓ)	COMMENTS	SOURCE
Australia	700	Victoria Plant	(1)
India	2100	tolerance limits	(1)
Mexico	1209	after mixing in discharge canal	(1)
Hungary	up to 3500	canning wastes	(1)
	1000-3000	sugar refinery	
	1112, 1602	two towns	
Belgium	1310-1905	canning wastes	(1)
Canada	420-2450	lagoon effluent	(2)
California	467-1295	aerated lagoons	(3)
California	1402	primary effluent	(4)
(various	1166	tricking filters	
plants)	918	activated sludge	
	1330	lagoons (ponds)	
SASKATCHEWAN			
Swift Current	1400-2000	secondary lagoon	(5)
Moose Jaw	1200-1600	secondary lagoon	(6)
Biggar	1024-2240	secondary lagoon	(7)
ALBERTA			
Red Deer	560	secondary lagoon	(8)
Medicine Hat	840	secondary lagoon	(8)
Hanna	1840	secondary lagoon	(8)
Brooks	1190	secondary lagoon	(8)
Taber	630-1260	secondary lagoon	(9)
S.E. Alta.	1050	potato dehydrating	(10)
Central Alta.	4900	cheese whey	(10)
S.E. Alta.	1260	meat packing	(10)
S.W. Alta.	1050	sour gas plant	(10)
S.Alta.	2590	N. fert. plant	(10)

1. Sullivan et al (1973)
2. Environment Canada (1984)
3. California State Water Resources Control Board (1984)
4. Pound and Crites (1975)
5. Jame et al (1984)
6. Underwood McLellan Ltd. (1978)
7. Wiebe (1982)
8. Regier and Wiskerke (1984)
9. Graveland (1982a)
10. Graveland (1982b)

*NOTE: EC values were converted to TDS using the factor 1 mS/cm = 700 mg/ℓ

IV. WATER QUALITY GUIDELINES: OVERVIEW

A. Introduction

A number of scientists have addressed the problem of water quality for irrigation (Wilcox, 1948: U.S. Salinity Laboratory Staff, 1954: Wilcox, 1958; Allison, 1964; Wilcox and Durum, 1965; Rhoades, 1971; Hart, 1974; Ayers and Westcot, 1976; Ayers, 1977; Christiansen and Olsen, 1977; Shainberg and Oster, 1978; and Westcot and Ayers, 1984). The U.S. Salinity Laboratory Staff (1954) manual on "Diagnosis and Improvement of Saline and Alkali Soils" is probably one of the most used references on salinity and irrigation water quality.

Ayers and Westcot (1976) compiled a document on water quality for agriculture with recommended guidelines that have been used extensively In 1984, they updated their guidelines and these are summarized in Table 2.

The approach used by Westcot and Ayers was to examine three major aspects of irrigation waters and their potential effect on both plants and soils. The three aspects were:

1. Salinity
2. Permeability
3. Specific Ions

Most provincial or state guidelines have tended to follow the examples set by Ayers and Westcot or by the U.S. Salinity Laboratory Staff (Handbook 60).

Table 2: Irrigation water quality guidelines (from Westcot and Ayers, 1984).

		DEGREE OF IRRIGATION PROBLEM		
		NO PROBLEM	INCREASING PROBLEMS	SEVERE PROBLEMS
SALINITY				
EC (mS/cm)		< 0.70	0.70 - 3.0	> 3.0
*TDS (mg/ℓ)		< 490	490 - 2100	> 2100
SAR (Permeability Effect on Soil)				
SARw			Irrigation Water (ECw)	
0 - 3		> 0.7	0.7 - 0.2	< 0.2
3 - 6		> 1.2	1.2 - 0.3	< 0.3
6 - 12		> 1.9	1.9 - 0.5	< 0.5
12 - 20		> 2.9	2.9 - 1.3	< 1.3
20 - 40		> 5.0	5.9 - 2.9	< 2.9
Specific Ions				
Sodium (Use SAR)	- most annual crops		- use salinity tables	
	- trees, woody ornamentals	< 3	3 - 9	> 9
Chlorides (mg/ℓ)	- most annual crops		- use salinity tables	
- trees, woody		< 140	140-350	> 350
Boron (mg/ℓ)	- general guideline	< 0.70	0.70 - 2	> 2

*TDS has been calculated by multiplying EC values by a factor of 700. For soil solution extracts, groundwaters, and possibly secondary effluents factors of 900 to 1000 are sometimes used.

B. "Revising" Guidelines For Irrigation Water Quality

There is an increasing demand for the use of lower quality water for irrigation as good quality waters become limited, particularly in arid regions where irrigation with poor quality water can at least ensure a crop. Similarly, there is an increasing demand from urban centers for the use of agricultural land for disposal of treated industrial and domestic sewage effluent. As a result of this increased demand, researchers are re-evaluating water quality guidelines. The purpose of this section of the report is to briefly review some current changes and emerging rationales.

1. Salinity

For standard irrigation with wastewaters, the Environment Canada (1984) manual indicates that waters with <1.3 mS/cm (less than 900 mg/ℓ) should present no problem, but waters with >3.0 mS/cm (greater than 2100 mg/ℓ) can cause severe problems. However, for irrigation with high leaching rates, the limit for no problems has been raised to <4.0 mS/cm (less than 2800 mg/ℓ). The rationale is that the higher leaching fraction will prevent excessive salt accumulation in the rooting zone.

Another common approach in the utilization of salty effluent waters is to grow plants that are salt tolerant. Thus, in sewage effluent irrigation projects, salt tolerant forages are often used replacing the less tolerant cereal varieties. There is a fair amount of documentation on the salt tolerance of various plant species although there is little that has been developed specifically under Canadian and Northern U.S. Prairie conditions (Kearney and Scofield, 1936; Bernstein, 1974; Ingvalson et al, 1976; Maas and Hoffman, 1977; McKenzie, 1983; Francois, 1981; and Maas, 1985).

Researchers have long recognized that soil texture plays an important role. Sandy soils are capable of handling larger salt loads with fewer adverse affects than finer textured soils. Internal drainage, depth to water table, and depth to less permeable materials particularly in shallow soil profiles can become critical. In fact, where poor quality irrigation waters are available soil suitability becomes increasingly important. Irrigation sites must be carefully selected to ensure that quality of water and soils are compatible.

2. Permeability

For a given soil texture, potential alteration of permeability of the soil becomes primarily a function of the SAR and EC of the irrigation water (ultimately soil water) and the type of clay mineral in the soil.

Bicarbonates also play a role in determining the equilibrium soil SAR. Ayers and Westcot (1976) utilized an Adjusted SAR in order to account for the bicarbonate effect. The authors of the Environment Canada (1984) manual on land application of treated municipal effluent felt that the Adjusted SAR calculations were too high for most wastewaters and favored the use of ordinary SAR's for their standards. Suarez (1981) introduced a new method (Adj. RNa) for estimating the SAR of soil or drainage water which more closely approximates ordinary SAR's. His approach has been considered more acceptable than the previous Adjusted SAR calculation (California State Water Resources Control Board, 1984).

High salinity can over-ride any potential effect of excess sodium (high SAR's) on infiltration. In fact, at a given SAR, the infiltration rate increases as

salinity increases. The high salt concentration (electrolytic concentration) counteracts any sodium induced displacement of the clay complex. The irrigation waters which present the worst problems with regard to physical impairment of the soil are waters that are relatively high in sodium and low in total salt content (Rhoades, 1977; Oster and Schroer, 1979; and Rhoades, 1982).

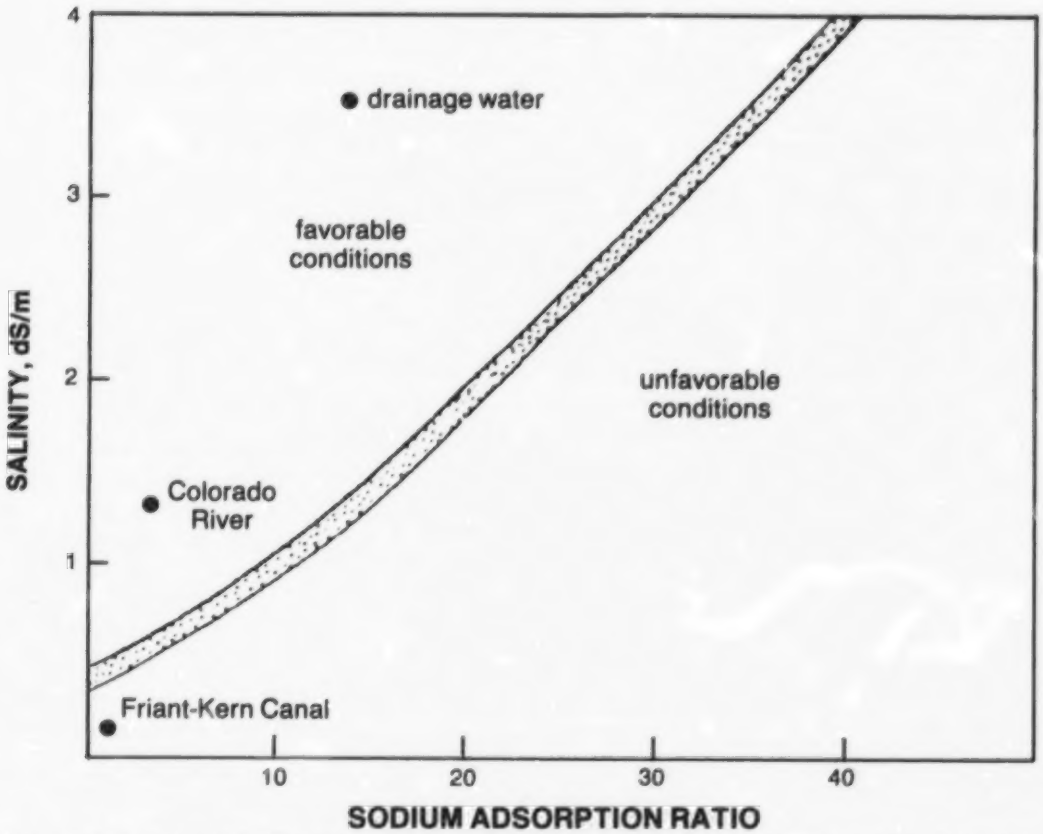


Figure 1: Relationship between salinity and sodium adsorption ratio showing combinations that promote good permeability and those which do not.

The broad line in Figure 1 represents a generalized boundary between stable and unstable soil physical conditions for the irrigation water or the soil solution (figure adapted from Oster and Rhoades, 1984). Combinations of salinity and SAR (or Adjusted RNa) values that lie above the line are not expected to cause dispersion or clay swelling. Those values that lie below the line can create permeability problems.

If the SAR in the topsoil is greater than 10, then large reductions in permeability can occur if rainfall reduces soil salinity to levels less than 1 mS/cm. Reductions of soil permeability below the surface are usually not a problem as the increased level of salinity due to removal of water by the crop should offset adverse effects of exchangeable sodium.

Texture, particularly clay content and the mineralogy or type of clays can be a determinant in the sodium permeability problem. The montmorillonite (2:1 crystal lattice) expanding clays present the largest problem with regards to colloidal particle dispersion and reduced permeability (Ayers and Westcot, 1976). The lesser illite-vermiculite (2:1 crystal lattice) clays are not as bad but

still present problems. The least affected clays are the kaolinites (1:1 crystal lattice) and sesquioxide clays. It would also follow that soils with low clay contents are less affected.

3. Other Problems

In addition to salinity and permeability, irrigation waters may contain other compounds which are toxic to crops. The following parameters are important:

1. Specific ion toxicity, e.g.: Boron (B), Sodium (Na) and Chloride (Cl^-) toxicity;
2. Trace elements and heavy metals;
3. Biological organisms;
4. Toxic organic chemicals;
5. Acid content (pH) and corrosion;
6. Plugging potential (drip systems); and
7. Others.

V. SALINITY

A. Crop Salt Tolerance

The salinity or total soluble salt concentration of irrigation water is an extremely important water quality consideration. An increase in salinity causes an increase in the osmotic pressure of the soil solution resulting in reduced availability of the water for plant consumption. Consequently, plant growth may be severely retarded.

Salt accumulation in the soil can be controlled by irrigation management or, more specifically, the volume of water applied. If the combined application of irrigation and rainfall is lower than plant consumptive use, an accumulation of salts will occur in the root zone. Properly managed irrigation will allow for application of sufficient excess water (called leaching fraction) to move a portion of the salts below the root zone.

Plants vary in their tolerance to soil salinity. As a general rule most fruit crops are sensitive followed by vegetable, field, and forage crops. Within a crop species different varieties may have different salt tolerances. In addition, tolerances vary with different stages of growth; usually the germinating seedling is the most sensitive (Millington et al, 1951 and Hart, 1974).

There is a large collection of world-wide literature available that deals with the relationship of the salt tolerance of plants to the salinity of irrigation water (Kearney and Scofield, 1936; Bernstein, 1964; Bernstein, 1965; Bernstein et al, 1972; Bernstein, 1974; Ayers and Westcot, 1976; Maas and Hoffman, 1977; Francois, 1981; Westcot and Ayers, 1984; Maas, 1985; Maas, 1986). Most of the data have been derived from sand tank experiments where high leaching fractions were maintained to obtain a uniform salt distribution throughout the root zone. Experience has confirmed that such data are reproducible and reliable and have the advantage of being transposed to field situations. Over the years, salt tolerance tables showing the relationship between plant sensitivity and irrigation water salinity have been derived from the data.

A salt tolerance table for some irrigated Canadian crops has been compiled taking into account the previously published literature (Table 3). The assumptions used to derive the salt tolerance ratings are presented at the bottom of the table. There have been several concerns about the use of the data in Table 3 for Canadian conditions.

1. The crop varieties used to derive the salt tolerance for Table 3 are not the same as our Canadian varieties and differences have been observed (McKenzie et al, 1983). Canadian wheat and barley varieties do not appear as salt tolerant as those listed in Table 3 and alfalfa might be more salt tolerant.

2. The derivation of the table is based on maximum tolerance without yield reduction of growing (established) plants but does not account for germination and seedling tolerance. Although barley and wheat are shown as very tolerant crops, actual soil electrical conductivities (ECe) should not exceed 4 to 5 mS/cm during the germination and seedling stages. ECe should not exceed 3 mS/cm for garden beets and sugar beets during germination.

Table 3: Salt tolerance of selected crops.

DEGREE OF TOLERANCE	FRUITS AND BERRIES	VEGETABLES	FIELD CROPS	FORAGES
NOT TOLERANT ECw < 0.7 TDS < 500	Strawberry Raspberry	Beans Carrots	Beans	
SLIGHTLY TOLERANT ECw < 1.2 TDS < 800	Boysenberry Currants Blackberry Gooseberry Plum Grape Apricot Peach Pear Cherry Apple	Onion Parsnips Radish Pea Pumpkin Lettuce Pepper Muskmelon Sweet Potato Sweet Corn Potato Celery Cabbage Kohlrabi Cauliflower	Cowpea Broadbean Flax Sunflower Corn	Clover (alsike, ladino, red, & strawberry) Berseem clover Corn forage
MODERATELY TOLERANT ECw < 2.2		Spinach Cantaloupe Cucumber Tomato Squash Brussel Sprouts Broccoli Turnips	Rice (paddy)	Brome, smooth Alfalfa Big Trefoil Beardless wildrye Vetch Timothy Crested wheatgrass
TOLERANT ECw < 3.6 TDS < 2500		Beets Zucchini	Canola Sorghum	Oat Hay Wheat Hay Mountain brome Tall Fescue Sweet Clover Reed canarygrass Birdsfoot trefoil Perennial ryegrass
VERY TOLERANT ECw < 5.0 TDS < 3500		Asparagus	Soybean Safflower Rye Wheat Sugarbeet Barley	Barley Hay Altai wildryegrass Tall wheatgrass

Assumptions:

- The crops within each "tolerant" grouping are not expected to incur any yield reductions. Actual tolerances will be modified by management, climate, and soil conditions. Within each group the relative tolerance of the crop is listed from least to most tolerant.

- ECw is the electrical conductivity of the irrigation water. TDS means total dissolved solids in units of mg/ℓ. The conversion factor of 1EC = 700 mg/ℓ has been used to transpose data.

- A leaching fraction of approximately 15% is maintained. The tolerance tables can be adjusted by increasing or decreasing the leaching fraction. It was assumed that ECsw = 3ECw for a leaching fraction of 0.15. ECsw is the electrical conductivity of the soil solutions.

- Soil texture ranges from sandy loam to clay with good internal drainage and no uncontrolled shallow water table.

- Rainfall is low and does not play a significant role in meeting crop demands.

- The use of gravity and sprinkler irrigation systems where water is applied infrequently as needed. The crop utilizes 50% or more of the stored available water before the next irrigation. Guidelines are too restrictive for frequent or drip irrigation systems.

- Each irrigation leaches the upper root zone and salt accumulation increases with depth. The crop responds to the average salinity in the root zone and the salt content of the soil solution (ECsw) is about three times that of the irrigation water (ECw) due to evapotranspiration.

* Adapted from Maas and Hoffman (1977) and Westcot and Ayers (1984).

3. There is concern by researchers that the data in Table 3 is more representative of Californian conditions than Canadian conditions. The climate in Canada is cooler and moister, suggesting that a higher natural leaching fraction occurs.

4. Much of the data has been derived using sandy soil or sand cultures, while the irrigated soils in Canada range from sands to clays. It has been felt that some compensation or adjustments for soil texture should be made.

B. Salt Accumulation In The Soil

To prevent the accumulation of salt in the soil, irrigation must provide sufficient water not only for crop growth (evapotranspiration) but also for leaching excess salts below the root zone. The fraction of water applied to the field that percolates through the soil profile and drains below the root zone is commonly referred to as the leaching fraction (LF).

Under irrigation a steady state salinity profile gradually develops in a well drained soil. The long-term salinity profile is controlled by the salinity of the irrigation water and increases with depth with the highest salinity value near the bottom of the root zone (Van Schilfgaarde et al, 1974 and Bower et al,

1969). The magnitude of the salinity in the profile is controlled primarily by the degree of leaching.

A concise model for predicting the steady-state salinity profile that would develop at the bottom of each depth segment for a given irrigation water with a salt concentration of ECw and a leaching fraction, LF, can be developed by using the following salt mass balance equation:

$$(Vw)\ (ECw) = (Vsw)\ (ECsw)$$

Where ECw and ECsw are the electrical conductivities of the irrigation and soil waters, respectively, Vw is the volume of applied irrigation water, and Vsw is the volume of soil water moving below a given depth segment. In order to convert ECsw to ECe (saturated paste extract) the conversion ECe = 0.5 (ECsw) is used which implies that the soil water content is maintained somewhere near field capacity.

The ratio Vsw/Vw is the leaching fraction (LF) and by dividing a soil into four depth segments the water uptake by the crop from each quarter of the root zone can be assumed to be 40, 30, 20, 10%. Assuming an overall LF of 20% the resultant leaching fractions at the bottom of each of the four soil segments would be 0.68, 0.44, 0.28, and 0.20. For an irrigation water having an ECw of 1 mS/cm the corresponding salt concentrations of the soil water would be 1.47, 2.27, 3.57, and 5.00 mS/cm. Averaging these salt concentrations over each segment and using the root distribution to calculate a weighted-average concentration, the average root zone soil water concentration becomes 2.06 mS/cm. Assuming the conversion of 2ECe = ECsw, then the average extractable electrical conductivity on saturated extracts of the soil (ECe) would be 1.03 mS/cm.

The above calculations can be repeated for any leaching fraction and the relationship between soil profile, salt accumulation and leaching fraction derived.

From such data and from tabulated salt tolerance data derived from Maas and Hoffman (1977), one can predict the yield reduction of various crops for given water qualities and leaching fractions. Utilizing the available information, expected yield reductions for some common crops have been calculated and are presented in Table 4.

C. Salinity Guidelines

The overall effect of the irrigation water on crop yield will depend upon crop tolerance and leaching fraction. Economics also enter the picture. For example, a yield decrease of 10% over optimum irrigation yield may not make a significant difference relative to the overall increase over dryland (non-irrigated) yield. Thus, at a leaching fraction of 10% (Table 4) an irrigation water of 2.0 mS/cm may cause a slight yield reduction but would a further yield reduction to 15% be a problem if the available water supply had an EC of 3.0 mS/cm (2100 mg/ℓ) rather than 2.0 mS/cm (1400 mg/ℓ)?

In addition to crop production and economics, the concept of long-term soil protection must be considered. What degree of salt accumulation in our soils can we allow from irrigation? This is a difficult question to answer. From a practical point of view, we do not mind an accumulation of salt in soils over and above their natural salt levels prior to irrigation provided we can achieve and maintain an increased economic productivity from the land base. However,

Table 4: Expected yield reductions (%) for various combinations of crop, leaching fraction, and irrigation water salt content.

CROP	ECw (mS/cm) 1.0	2.0	3.0	4.0	5.0
	LF = .10 (Factor = 1.36)				
Wheat	0	0	0	0	6
Crested Wheatgrass	0	0	2	8	13
Alfalfa	0	5	15	25	35
Potatoes	0	12	28	45	61
Strawberries	12	100	100	100	100
	LF = .20 (Factor = 1.03)				
Wheat	0	0	0	0	0
Crested Wheatgrass	0	0	0	3	7
Alfalfa	0	1	8	16	23
Potatoes	0	4	17	29	42
Strawberries	1	35	69	100	100
	LF = .30 (Factor = 0.87)				
Wheat	0	0	0	0	0
Crested Wheatgrass	0	0	0	0	3
Alfalfa	0	0	5	11	17
Potatoes	0	1	11	22	32
Strawberries	0	25	54	83	100

if the land were returned to dryland farming would the same salinity levels be considered deleterious to dryland crop production?

The effect of texture or drainage on salinity guidelines will be discussed in later sections. The salt accumulation models assume ideal drainage conditions and ideal management. With finer textured soils these conditions may not be as easy to achieve and guidelines may wish to reflect this.

In Saskatchewan, a general salinity guideline for irrigation water would be in the order of 1000 mg/ℓ (EC = 1.4 mS/cm). For most cereal and forage crops this should ensure adequate protection with no yield reductions while preventing degradation of long-term soil quality where leaching fractions are maintained above 10%.

VI. SODIUM ADSORPTION RATIO, BICARBONATES AND PERMEABILITY

A. SAR and Salinity

Excess sodium in the irrigation water relative to calcium and magnesium or relative to the total salt content can adversely affect soil structure and reduce the rate at which water moves into and through the soil (permeability, infiltration) as well as reduce soil aeration. When calcium is the predominant cation on the soil exchange complex, the soil tends to have a granular structure that is easily worked and permeable. Sodium can adversely affect the physical condition of soil so that when the soil is wet it disperses clay particles or "runs together" and becomes very tight. Water will not easily move through a soil when it is in this condition. When adsorbed sodium exceeds 10 to 15% of the total cations clay particles are dispersed resulting in a soil that becomes puddled when wet, lowering permeability and forming a hard impermeable crust when dry.

The magnitude of the effect of excess sodium can be related to the relative proportions of sodium ions and calcium plus magnesium ions in the irrigation water. The sodium adsorption ratio (SAR) can be calculated as follows:

$$SAR = 0.275\ (Na) \ /\ SQRT\ [(Ca) + 1.64\ (Mg)]$$

where concentrations of Na, Ca, and Mg are expressed as mg/ℓ.

Most researchers agree that when the SAR approaches 10, the probability for soil permeability problems increases. However, the potential permeability effects of SAR can often be counteracted by high salt levels. Quirk and Schofield (1955) and Quirk (1971) have shown that there is a clear advantage in increasing the salinity in the irrigation water to maintain soils in a flocculated and, hence, permeable condition. As discussed previously, irrigation with water relatively high in sodium and low in total salt content may result in poor soil physical conditions while high sodium waters with high salinity provide stable conditions. The generalized boundary between stable and unstable soil conditions was shown in Figure 1 (from Oster and Rhoades, 1984).

B. Bicarbonate Hazard (Adjusted SAR's)

The sodium adsorption ratio can be altered by the presence of excess bicarbonate in the irrigation water. The bicarbonate hazard as discussed by Eaton (1950) refers to long-term use of irrigation waters containing high concentrations of bicarbonate. As the bicarbonate becomes concentrated in the soil water due to evapotranspiration, there is an increased tendency for calcium and magnesium to be precipitated as insoluble carbonates. Over time this will result in an increased SAR and the appearance of sodium problems (Bower et al, 1968; and Rhoades, 1968).

Several researchers over the past decade have made attempts to quantify the potential bicarbonate hazard ranging from calculating residual sodium carbonate (RSC) values (Eaton, 1950; Wilcox, 1958) to calculating adjusted SAR's (Bower et al, 1968; and Rhoades, 1971). The adjusted SAR calculation is as follows:

$$\text{Adj. SAR} = \text{SAR}\ (1 + 8.4 - \text{pHc})$$

where pHc is a complex term (accounting for the precipitation of Ca and Mg as carbonates) that can be calculated using tables given in Ayers and Westcot (1976).

It was thought at the time that one of the advantages of the water quality criteria proposed by Ayers and Westcot (1976) was that it introduced a method of accounting for the effect of carbonates and bicarbonates in irrigation water on the precipitation of calcium and magnesium. But Canadian experience has shown that the adjusted SAR calculations are often 2 to 3 times the SAR for many waters. It was felt that the calculated adjusted SAR's might tend to over-compensate for a potential bicarbonate hazard (Environment Canada, 1984).

The approach of Suarez (1981) for estimating SAR has been adopted by Westcot and Ayers (1984), and appears to yield SAR values similar to the standard SAR calculation. Westcot and Ayers (1984) in deriving their tables made the simplifying assumption that the partial pressure of CO2 (pCO2) in the soil air near the surface was 0.0007 atmosphere.

Suarez (1981) derived several alternative methods for calculating adjusted SAR's based on known equilibria relationships. This was a step beyond derivation of empirical constants (mineral weathering parameter) by the use of curve-fitting equations (Rhoades, 1968). The Suarez (1981) expressions showed a good fit to the experimental lysimeter data of Oster and Rhoades (1975) using the appropriate leaching fraction, partial pressure of CO2 and HCO3/Ca ratio.

Suarez (1981) suggests that the near-surface soil environment is usually characterized by a pCO2 level slightly above that of the applied irrigation water. Most irrigation waters from surface sources in arid areas are supersaturated with calcite, but at a level of saturation where precipitation of CaCO3 is negligible. For such conditions, the SAR of the irrigation water will be a suitable indicator of the resultant near-surface soil water SAR and the exchangeable sodium percentage (ESP) of the soil under steady-state conditions.

Bingham et al (1979) found good agreement between SAR of the irrigation water and the ESP of the top 0.3 m of a soil irrigated with four different waters. Although the exchangeable sodium percentages (SAR's) were very low (less than 5), the results are consistent with the above reasoning and with computer model predictions. However, if irrigation is infrequent, nonuniform, or both, near-surface SAR's will be greater than predicted, as will salinity. In those instances a reasonable estimate of near-surface soil water SAR may be obtained by allowing for concentration of the applied water (by evaporation). The use of groundwater for irrigation (especially irrigation drainage water) will usually result in large degrees of super-saturation after degassing of CO2. For these waters, the appropriate pCO2 value should be chosen (e.g. 0.0007 atm) and SAR calculated by Suarez's equation and Table 5. In this instance, use of SAR values of the irrigation waters would be expected to underpredict the SAR of the soil water near the surface, and thus surface-ESP values.

Suarez's equation is as follows:

$$\text{Adj. RNa} = [Na/LF] / \text{SQRT}\,[Mg/LF + X\,(pCO2)\ 1/3]$$

where concentrations of Na, Mg, and X are expressed as mmoles/L, LF is the leaching fraction (usually assumed to be 1.0 at the soil surface), and pC02 is the partial pressure of carbon dioxide (usually assumed to be 0.0007 atmospheres near the soil surface). The value of X in mmoles/L can be obtained from Table 5 by calculating the HC03/Ca ratio and the ionic strength (u). A convenient and direct method for estimating the ionic strength of a solution is to use the relationship derived by Griffin and Jurinak (1973), viz,

$$u = 0.013\ (EC)$$

where u is the ionic strength based on concentrations expressed in mmoles/L and EC is the electrical conductivity expressed in mS/cm @ 25 degrees C.

A comparison of the various adjusted SAR and RNa calculations for some Saskatchewan waters is presented in Table 6. The adjusted SAR calculations proposed by Rhoades (1968) were generally 2-3 times higher than the standard SAR calculation. The Suarez (1981) calculations (last 2 columns) were slightly higher than the noraml calculated SAR, increasing as the potential sodium hazard from bicarbonates increased. The second last column was calculated using the Suarez (1981) equation and values from Table 5. The last column was caluclated using Westcot and Ayers (1984) modification. The results for the last two columns should be comparable; differences are due to tabular interpolation.

Table 5: X values calculated from Eq. (20) for various $HC0_3$/Ca ratios and ionic strength.

	IONIC STRENGTH														
HCO_3/Ca	0.001	0.005	0.01	0.02	0.03	0.04	0.05	0.07	0.1	0.15	0.2	0.25	0.3	0.4	0.5
0.1	73.4	79.6	84.1	90.0	94.4	97.9	101.0	106.0	112.0	120.0	125.0	130.0	133.0	139.0	144.0
0.2	46.2	50.1	53.0	56.7	59.5	61.7	63.6	66.8	70.5	75.3	78.8	81.7	84.0	87.7	90.4
0.3	35.3	38.2	40.4	43.3	45.4	47.1	48.5	51.0	53.8	57.5	60.1	62.3	64.1	67.0	69.0
0.4	29.1	31.6	33.4	35.7	37.5	38.9	40.1	42.1	44.4	47.4	49.6	51.5	52.9	55.3	57.0
0.5	25.1	27.2	28.8	30.8	32.3	33.5	34.5	36.3	38.3	40.9	42.8	44.3	45.6	47.6	49.1
0.6	22.2	24.1	25.5	27.3	28.6	29.7	30.6	32.1	33.9	36.2	37.9	39.3	40.4	42.2	43.5
0.7	20.1	21.7	23.0	24.6	25.8	26.8	27.6	29.0	30.6	32.7	34.2	35.4	36.4	38.1	39.2
0.8	18.3	19.9	21.0	22.5	23.6	24.5	25.2	26.5	28.0	29.9	31.3	32.4	33.3	34.8	35.9
0.9	17.0	18.4	19.4	20.8	21.8	22.6	23.3	24.5	25.9	27.6	28.9	30.0	30.8	32.2	33.2
1.0	15.8	17.1	18.1	19.4	20.3	21.1	21.8	22.8	24.1	25.8	26.9	27.9	28.7	30.0	30.9
1.5	12.1	13.1	13.8	14.8	15.5	16.1	16.6	17.4	18.4	19.7	20.6	21.3	21.9	22.9	23.6
2.0	9.96	10.8	11.4	12.2	12.8	13.3	13.7	14.4	15.2	16.2	17.0	17.6	18.1	18.9	19.5
2.5	8.58	9.31	9.84	10.5	11.0	11.5	11.8	12.4	13.1	14.0	14.6	15.2	15.6	16.3	16.8
3.0	7.60	8.24	8.71	9.33	9.78	10.1	10.5	11.0	11.6	12.4	13.0	13.4	13.8	14.4	14.9
3.5	6.86	7.44	7.86	8.42	8.82	9.15	9.44	9.91	10.5	11.2	11.7	12.1	12.5	13.0	13.4
4.0	6.27	6.80	7.19	7.70	8.07	8.37	8.63	9.06	9.57	10.2	10.7	11.1	11.4	11.9	12.3
4.5	5.80	6.29	6.65	7.12	7.46	7.74	7.98	8.38	8.85	9.45	9.88	10.2	10.2	11.0	11.3
5.0	5.41	5.86	6.20	6.63	6.96	7.22	7.44	7.81	8.25	8.81	9.21	9.55	9.83	10.3	10.6
6.0	4.79	5.19	5.49	5.87	6.16	6.39	6.59	6.92	7.30	7.80	8.16	8.46	8.70	9.09	9.37
7.0	4.31	4.68	4.95	5.30	5.56	5.77	5.95	6.24	6.59	7.04	7.36	7.63	7.85	8.20	8.45
8.0	3.95	4.29	4.53	4.85	5.09	5.28	5.44	5.71	6.03	6.44	6.74	6.98	7.18	7.50	7.73
9.0	3.65	3.96	4.19	4.48	4.70	4.88	5.03	5.28	5.57	5.95	6.23	6.46	6.64	6.94	7.15
10.0	3.41	3.69	3.90	4.18	4.38	4.55	4.69	4.92	5.20	5.55	5.80	6.02	6.19	6.46	6.66

Table 6: Comparison of SAR, Adjusted SAR and Adjusted RNa Calculations on Selected Saskatchewan Waters.

WATER SOURCE	EC	Na	Ca	Mg	HCO3
Rivers	(mS/cm)	----------mg/ℓ----------			
South Sask.	.39	17	48	18	172
Qu'Appelle	1.31	159	87	55	659
LAGOON					
Swift Current	2.71	320	162	125	500
Govan	3.80	465	202	167	550
GROUNDWATER					
Tyner Valley (Donavon)	3.15	700	85	70	440
Hatfield Valley (Watrous)	4.10	915	110	90	410
	SAR (1)	**SAR (2)**	**Adj. RNa (3)**	**Adj. RNa (4)**	
RIVERS					
South Sask.	0.53	1.03	0.58	0.59	
Qu'Appelle	3.71	10.02	4.64	4.64	
LAGOON					
Swift Current	4.60	13.34	5.56	5.56	
Govan	5.86	17.60	7.06	7.21	
GROUNDWATER					
Tyner Valley	13.63	32.7	15.86	15.80	
Hatfield Valley	15.67	40.0	18.24	18.23	

1. SAR = Na / SQRT [(Ca + Mg) / 2] (meq/ℓ)
2. From Rhoades (1968) and Ayers and Westcot (1976)
3. From Suarez (1981)
4. From Westcot and Ayers (1984)

C. Rainfall Effect

Irrigation with water relatively high in sodium and low in total salt content may result in poor soil structure while high sodium water with high salinity provide stable conditions (Figure 1).

There is a tendency to emphasize the effect of SAR on soil permeability rather than on other soil conditions. Of importance, but not well documented are problems associated with tilth, seedbed preparation and reduced germination. Increased wear of cultivator shovels and horsepower requirements also are a consideration for high SAR in soils (McMullin, 1985).

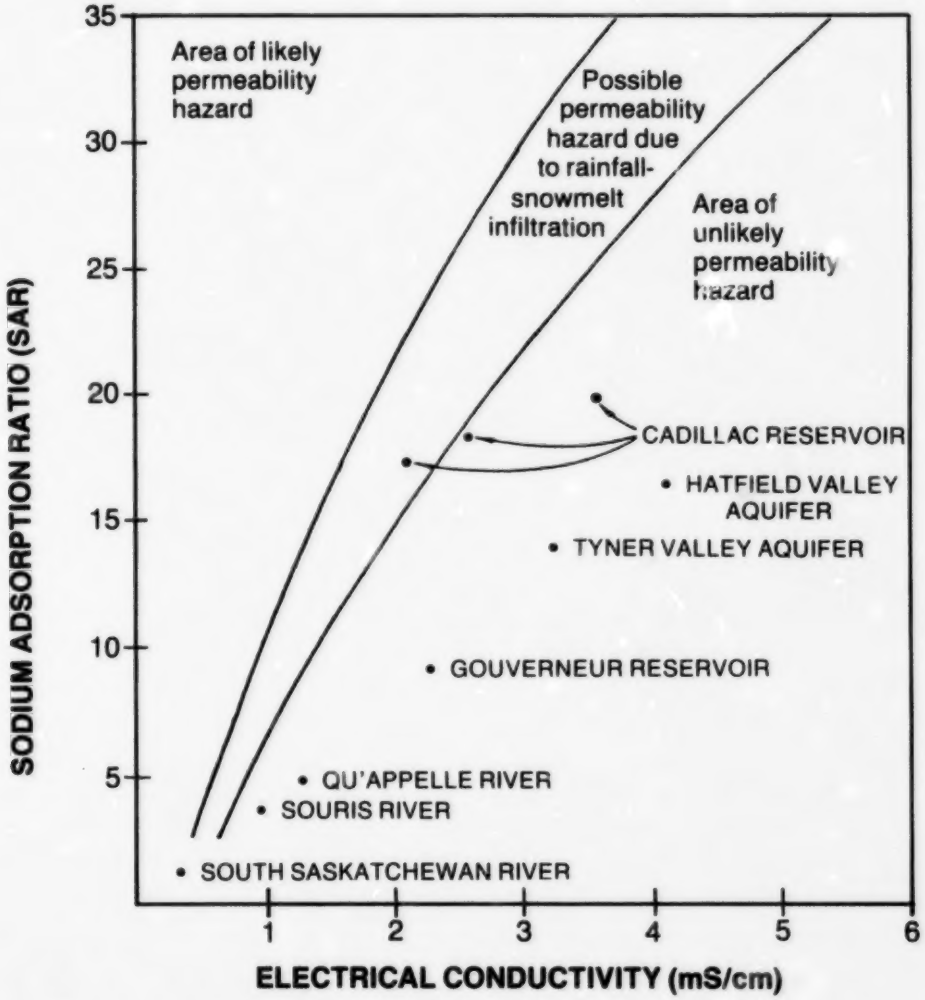
The potential effect of rainfall and snowmelt in inducing a sodium hazard has not been well documented. Figure 1 was originally derived for dry climates where rainfall was insignificant relative to applied irrigation water (California conditions). However, in Saskatchewan natural precipitation plays an important role in crop production. In the spring, snowmelt infiltration and rain showers can temporarily dilute the surface salt concentration without affecting the exchangeable sodium percentage. As an example, if the SAR of the topsoil is greater than 10, then large reductions in permeability (puddling, crusting) can

occur if rainfall reduces soil salinity to levels less than 1 mS/cm (Figure 1). In Saskatchewan's climate this becomes important. Precipitation can temporarily dilute the surface salt concentration, but have only minor effects on the ESP of the soil.

It may be realistic under these situations to provide some degree of protection by extending the zone of potentially unstable conditions downward, particularly for more saline waters. Thus, the heavy solid line in Figure 2 is more representative of conditions in Saskatchewan. Irrigation waters with EC of 1 mS/cm or more and SAR of 6 or less would maintain stable conditions. Waters with EC near 3 should not cause permeability problems if SAR's were less than 20 as opposed to 30.

The heavy solid line in Figure 2 is only an approximation of real conditions. It was assumed that rainwaters and spring meltwaters could temporarily reduce the surface salt concentration by one-third (without appreciably altering the ESP). According to Oster and Rhoades (1984), a 33% loss of soluble salts can be achieved by intermittent ponding of about 4 cm of fresh water on 15 cm of surface soil.

Figure 2: Salinity-SAR relationship with safety-factor for rainfall dilution effects.



VII. SOIL SUITABILITY CLASSIFICATION

A. Background

A number of irrigation suitability classification systems have emerged over the past decades (Bowser and Moss, 1950; Fly, 1961; Canada Department of Agriculture, 1964; and Maletic and Hutchings, 1967). Many of the previous methods were based on rating systems and criteria relevant to flood or gravity irrigation systems. However, with the popularity of the wheel roll and center pivot systems the older schemes became outdated. For example, factors such as level terrain and stoniness, although always carefully considered, became less important.

The recent development of a new manual for land irrigation classification by Alberta Agriculture was a major step forward (Alberta Land Classification Branch Staff, 1983). Their classification combined information from filed soil surveys (partly using modified FAO (1979) criteria for various ratings) with a topography classification to define six land classes for irrigation suitability.

Another recent development on irrigation suitability classification has been the establishment of a Working Group on Irrigation Suitability Classification (Western Canada) by the Expert Committee on Soil Survey (Working Group on Irrigation Suitability Classification, 1985). The final draft of a revised irrigation land classification scheme for Western Canada has almost been completed by the Working Group and the system should prove to be very valuable for years to come. The approach uses both soils and topographical information and rates the severity of restrictions for irrigation. It is not as methodology (field survey) orientated as the Alberta system and permits a fair degree of flexibility depending upon the scale of mapping.

In the new system an irrigation land class is determined by combining information on both soil and landscape into a ranking matrix. Four general land suitability classes can be assigned (and more sub-classes as required). The four classes are described as excellent (Class 1), good (Class 2), fair (Class 3), and poor (Class 4). A brief description of these classes is presented below:

CLASS	RATING	DESCRIPTION
Class 1	Excellent	Lands in this class have no significant limitations for irrigation.
Class 2	Good	Lands in these classes have slight limitations for irrigation. The soils in these classes may be heavier or lighter in texture than soils in Class 1.
Class 3	Fair	Lands in these classes have moderate limitations for irrigation. The soils may be inferior because of excess salinity, sodicity, very low hydraulic conductivity or low water holding capacity.

Class 4	Poor	Lands in these classes have severe limitations for irrigation. Sub-surface drainage can sometimes be used to upgrade these soils where high water tables are a problem.

B. Desirable Soil Characteristics

The most important factors affecting the irrigation suitability of soils are those which affect the intake, transmission, and retention of water. The U.S. Bureau of Water and Power (1980) have described the soil-water requirements for profitable, diversified crop production under sustained irrigation as:

** Adequate moisture holding capacity.
** Adequate internal soil drainage.
** Adequate infiltration rates.
** Sufficient depth of suitable material.
** Suitable texture, structure and consistency.
** Absence of injurious amounts or salinity, sodicity or toxic elements.

C. Important Soil/Landscape Factors

The primary objective of this study is to provide a set of soil and water quality guidelines for irrigation projects in Saskatchewan where both the quality of the water and soil compatibility for irrigation are considered together. Often, soil and landscape criteria for irrigation are developed assuming good quality water; and just as often, water quality criteria for irrigation are developed assuming that soils are well drained and suitable for irrigation.

When the two approaches are combined, a large variety of interactions are possible. From the point of view of effects of salts, sodicity, and other elements in the irrigation water on soils, certain soil and landscape factors usually considered in irrigation classification systems is presented in Table 7. The factors are defined using excerpts from the report of the Working Group on Irrigation Suitability Classification (1985) and then briefly discussed as to their importance in determining irrigation water-quality (salt, sodicity) interaction with the soil.

As can be seen in Table 7, there are a large number of soil and landscape factors that influence the criteria for irrigation suitability and, often, these same factors are important in determining the quality of water which can safely be applied to an irrigation land area.

Two prominent factors which appear to have a large influence on determining soil-irrigation water compatibility are texture and drainage. Texture plays a role in determining infiltration and permeability of a soil and thus influences the leaching fraction. In addition, texture is important in the soil exchange complex. The second factor drainage or drainability is a very broad term which is influenced by a large number of factors including texture, depth to bedrock, depth to water table, and topography or landscape position. Good drainage is required to ensure an adequate leaching fraction for removal of salts from the root zone.

Table 7: Soil and landscape factors usually affecting irrigation suitability evaluation.

FACTOR	COMMENTS
Texture	Texture refers to the relative proportions of sand, silt and clay which compromise the soil's mineral component. Texture strongly influences important soil water properties such as available moisture holding capacity, hydraulic conductivity, and infiltration rate which all have a significant effect on irrigation suitability. Texture also plays a major role in the soil exchange complex. Soil texture is an important soil compatibility criteria for irrigation water quality.
Structure	Soil structure refers to the degree of aggregation of soil particles. Structure in combination with texture is very important in determining permeability, intake rates and hydraulic conductivity. Solonetzic soils with strong B horizons and massive clay soils are two examples of where structure can reduce soil permeability. However, structure is generally not considered to be a dominant factor affecting the chemical interactions of irrigated water in the soil. The converse is not true; salt composition can adversely affect structure.
Available Water Holding Capacity	The available water holding capacity (AWHC) is generally considered to be equivalent to the amount of water retained in the soil between field capacity and permanent wilting point, i.e. up to 15 bars water pressure. AWHC is directly related to soil texture. Soils with extremely low water holding capacities are considered to be inefficient for sustained large scale irrigation. Available water holding capacity is generally well correlated with soil texture and this factor is best reflected by texture.
Hydraulic Conductivity	Saturated hydraulic conductivity (Ksat) refers to the rate at which water will move through a saturated soil (mm/hr). It is an important factor in evaluating soil water regimes for irrigation, particularly for the engineering and designing of systems. Hydraulic conductivity gives an indication of the drainability of a soil. The Ksat of the root zone must be fast enough to drain water from saturated

soils within 2 days to prevent aeration problems and yield losses. The lower zone must be sufficiently permeable to prevent build-up of the water table under irrigation. Although hydraulic conductivity is an important factor in irrigation soil-water compatibility, it's importance comes about indirectly and may be reflected in texture, drainability, and depth to the water table. Application rates can be adjusted to match soil hydraulic conductivity, but the overall rate of water movement must be such to ensure an adequate leaching fraction (also see section on hydrogeology).

Geological Uniformity

The uniformity of geologic deposits generally refers to the uniformity of permeability, which has a major bearing on soil drainability, water retention, and water table regimes. The change in permeability with respect to depth may limit the suitability of soil for irrigation. The presence of less permeable strata can be restrictive from the viewpoint of possible water table build-up. In terms of compatibility criteria, geological or spatial uniformity becomes an important aspect of the whole idea of drainability and depth to water table.

Depth to Bedrock

Refers to the thickness of permeable material over consolidated or poorly weathered bedrock. The proximity of bedrock to the ground suface will affect soil moisture regimes, water tables, and soil drainage. Depth to bedrock is a major consideration for artificial drainage design and installation. From the water quality-soil compatibility perspective, the depth to bedrock criteria is really a measure of depth of permeable material over less permeable material and thus falls in the geological uniformity category. As such, it may be more related to drainability and depth to water table.

Intake Rate

Intake rate refers to the movement of irrigation water from the surface into and through the soil. It is the expression of several factors including infiltration and percolation. The amount of moisture already in the soil greatly influences the rate at which water enters the soil. As the soil gradually becomes saturated, the intake rate decreases until it reaches a nearly constant value. The soil layer with the lowest

transmission rate, either at the surface or below it, usually determines the intake rate. Intake rate (infiltration, percolation) is important in engineering design criteria. Its influence on irrigation water quality-soil compatibility would be through its influence on the leaching fraction required under irrigation.

Drainage Class

Drainage refers to the rate of removal of water from a soil in relation to supply. Drainage is a very important irrigation water quality-soil compatibility criterion. Without adequate drainage, waterlogging, salt accumulation and eventual salinization can become a problem. Drainage is influenced by a large number of soil factors, generally integrated in nature. Factors which can strongly influence drainage and often are interrelated include texture (and structure), hydraulic conductivity (percolation), geological (spatial) uniformity, depth to bedrock, depth to water table, and topgraphy. Soil drainage classes include:

- Very rapidly drained
- Rapidly drained
- Well drained
- Moderately well drained
- Imperfectly drained
- Poorly drained
- Very poorly drained

Depth To Water Table

Depth to water table (DWT) refers to the depth to the continuously saturated soil zone. Depth to water table is generally shallowest during the early spring but varies throughout the growing season. DWT is a very important soil water quality-compatibility criteria in that it helps determine the drainability of a soil. High water tables often contribute to salinity problems.

Salinity

Salinity is a measure of the relative concentration of soluble salts in the soil that may affect the growth of intended crops. The effects of salinity, particularly at the lower levels may not be as severe under optimum irrigation conditions. Under irrigation, it may be possible to dilute the soil solution to minimize the adverse effects of salinity. However, salinity is often an indication of poor drainage and high water tables. Saline soils are generally not recommended for irrigation.

Sodicity	Sodic soils contain sufficient sodium salt so that SAR values exceed 6. A high sodicity value can adversely affect soil structure and soil permeability. High sodium levels can be toxic to certain crops. Permeability problems associated with sodicity are problems in strong solonetzic soils. However, providing there is adequate drainage these soils can be irrigated.
Organic Matter	Organic matter is the humified (decomposed) material in soil. It can influence available water holding capacity, hydraulic conductivity, erosion, crusting, etc. Organic matter can play an important role in the biological decomposition of secondary effluent waters. Organic matter and depth of solum are two important factors in biological decomposition.
Topography	Topography refers to the frequency and steepness of slopes. Topography can influence the method of irrigation, but usually topography and its influence on the groundwater regime determine limitations for irrigation. From the viewpoint of irrigation water quality-soil compatibility guidelines of particular importance are the influences of topography on drainage and water table depths over the landscape.
Average Local Relief	Local relief refers to the vertical distance between depressions and knolls and is closely associated with complexity and steepness of slope. Local relief may necessitate special design for irrigation systems. Like topography, local relief can play an important role in drainage and local water table build-up.
Stoniness Classes	Stoniness refers to the percent of ground surface covered by stones. From a water quality compatibility point of view, it is not important.
Inundation (Flooding Frequent)	Inundation refers to the frequency of annual, or seasonal flood events which might be expected to adversely affect the crops or the management of the irrigation system. From a compatibility prespective, flooding can increase the leaching fraction, provided adequate drainage is available to remove the floodwaters.

Potential Fringe Area Impact	This factor should be considered where conditions are such that adjacent non-irrigated areas of soil or crop may be adversely affected by irrigation practices. The adverse effects may be increased water tables, occurrence of wet areas, or salinization. Non-target areas are often overlooked or ignored in most irrigation suitability guidelines. The effect of irrigation on local hydrology is often too complex (too many unknown factors) or costly to predict, prior to initiation of the irrigation scheme.
Infiltration Variability	Infiltration refers to the surface ponding potential of irrigated soils. This condition could occur due to very complex patterns of soils as a result of textural or structural variability. Topography or local relief also plays a major role in the spatial variability of infiltration. The problem is similar to geological uniformity and, in the end, becomes a drainage related problem on a 3-dimensional scale.

D. Hydrogeology

In establishing an irrigation regime, the hydrology must be assessed in three dimensions. Although existing guidelines for the classification of irrigable lands include criteria for the collection and analysis of limited groundwater and geology data, the established approach has tended to emphasize the soil charactertistics of the upper (1.5 m) zone. Without sufficient hydrogeologic input, the potential problems created by transient groundwater mounding due to irrigation recharge, cannot be taken into account. In order to obtain the hydrogeologic data necessary to properly evaluate such potential long-term problems, a comprehensive groundwater and geology field study is usually required. This investigation should be performed very early in the irrigation feasibility stage.

The rate which water is transmitted within any geologic profile is governed primarily by the saturated hydraulic conductivity and saturated thickness above a barrier of low permeability. It is important to gain an appreciation for the sensitivity of the water table response to long-term irrigation and to recognize specific soil-types that are transiently sensitive to irrigation.

The groundwater system is usually considered to be comprised of two related components: local and regional contributions. Local groundwater flow regimes and studies of these regimes are often limited to small areas. The groundwater flow in these areas is largely influenced by local topography and relief and the presence of water bodies such as sloughs. The amount of water percolating to the groundwater will vary from location to location with the low relief positions generally providing the bulk of the contribution.

The regional groundwater regime reflects the contributions of all the local groundwater flow regimes. Generally, the regional groundwater flow regime is considered on a watershed basis. The unconfined groundwater will flow from a topographic high to a topographic low, usually a creek or river. Along the way, there will be perturbations in this system caused by local flow patterns. The regional groundwater system is largely influenced by climate and man-made activities, but can have cyclic and seasonal variations depending upon weather conditions.

The regional groundwater flow regime provides the base groundwater level for local areas. Thus, upslope activities that alter the upslope hydrological regime can impact downslope through a change in the base groundwater level.

These impacts are often not well documented in irrigation studies because they are difficult to measure or predict and are usually long-term impacts. They can include off-target increases in hydraulic loading and resulting increase in salinization, as well as, return flows to the river systems resulting in some water quality degradation (Cameron, 1986). An intensive review of these impacts will not be made in this report.

VIII. ROLE OF SOIL TEXTURE IN GUIDELINES

A. Background

Soil texture plays a major role in irrigation. It is closely related to the ability of a soil to percolate water (permeability, infiltration), to store water (available water holding capacity) and to adsorb-desorb chemical ions (exchange capacity). Soil texture has been a critical factor in irrigation design and scheduling but has not received the attention it may merit in setting irrigation water quality-soil suitability guidelines.

Most researchers, field advisors and farmers know that poor quality water used to safely irrigate sandy soils will sometimes cause problems on clay soils. Several state and local agencies have attempted to include texture as part of their general irrigation water quality guidelines (A & L Laboratories, 1978; Anonymous, 1979; Soil Conservation Service, 1982; and Schafer, 1984). Not only texture but the types of clays present can influence soil reaction. Ayers and Westcot (1976) indicated that sodium reduces the permeability of soils having montmorillonite type clays more than in soils having illite-vermiculite clays, and kaolinite-sesquioxides clays are least affected. However, this same criteria was deleted from their recent guidelines for municipal wastewaters (Westcot and Ayers, 1984).

Table 8: Summary of some guideline adjustments for texture.

	SOIL TEXTURE				
	VERY COARSE	COARSE	MEDIUM	MEDIUM FINE	FINE
MONTANA					
Max EC	5.0	4.5	3.0	3.0	2.5
Max SAR	24.0	15.0	15.0	12.0	9.0
NORTH DAKOTA					
Max EC for:					
SAR < 4	3.0	3.0	3.0	2.25	0.75
SAR < 6	3.0	3.0	2.25	2.25	0.75
SAR < 8	3.0	3.0	2.25	0.75	0.75
SAR < 12	3.0	2.25	2.25	R	R
SAR < 15	0.75	0.75	R*	R	R
SOUTH DAKOTA					
Max EC for:					
SAR < 6	2.5	2.5	2.3	1.8	1.6
SAR < 8	2.2	2.2	2.0	1.5	1.4
SAR < 11	1.9	1.9	1.6	R	R
A & L LABORATORY					
Max EC for:					
Soil SAR < 4	1.4	1.4	1.1	1.0	0.8
Soil SAR < 6	2.9	2.9	2.3	2.1	1.8
Soil SAR < 8	4.4	4.4	3.5	3.2	2.9

*Restricted

A summary of the guidelines which take into account texture for determining maximum salinity and SAR levels in irrigation water is presented in Table 8. Table 8 is somewhat misleading as only a portion of the guidelines has been extracted. The reader is referred to the original references for further detail on these guidelines.

The actual Montana guidelines are similar to those proposed by Ayers and Westcot (1976). The textural information at the back of their guidelines, however, shows that irrigation waters as high as 5.0 mS/cm have been used on sandy and loamy sand soil. The guidelines for North and South Dakota are much more restrictive and vary with SAR. These guidelines tend to follow the water classification scheme that was presented in the U.S. Salinity Laboratory Handbook 60 (1954).

The A & L (1978) guidelines suggest that sands can usually handle irrigation waters with twice the salt concentration than clay soils and maintain a similar salt level in the soil. The premise used by A & L is that it is more difficult to leach fine textured soils than coarse textured soils. Consequently, irrigation waters recommended for use on fine textured soils are lower in salt and have a lower leaching requirement than waters recommended for coarse and medium textured soils. The A & L (1978) guidelines are similar to the guidelines published by the Kansas Cooperative Extension Service (1975).

Depth and vertical uniformity of soil is a criterion similar to depth to water table - the deeper the better. Usually a deeper soil assures more uniform infiltration as well as more soil mass and surface area for soil chemical and biological action. This is important in the putrefication of the wastewater and provides a larger root zone for the uptake of the added nutrients from wastewater application. Further, soil permeability usually decreases where the subsoil contacts denser underlying material. Where the denser materials are near the surface the chance for reduced leaching, ponding and lateral movement to lower depressions increases. The South Dakota guidelines (Anonymous, 1979) include some criteria to distinguish depth of permeable soil over less permeable soil and vice versa, in determining salinity and SAR guidelines.

B. Rationale

Soil texture should be included as part of the guidelines particularly in determining levels of SAR and salinity that provide permeability and salt tolerance protection. It is also a fact that insufficient rationale has been published in the scientific literature to include texture categories as a standard part of the EC-SAR guidelines. The North and South Dakota guidelines have been based on field data and experience with the use of salty and high SAR waters for irrigation (mainly groundwater). The A & L and Kansas guidelines are really based on different leaching fractions, with the premise that sandy soils will have higher leaching fractions than clay soils. The Montana information on textural groupings (Schafer, 1984) was derived from some of the accumulated Dakota data.

Although the complete rationale for textural categorization may not be in place, it is felt that textural grouping of soils with regard to water quality is in order. This would provide a soil suitability - water quality compatibility guideline for the protection of soils.

In addition to field experience, perhaps primary rationale is that clay soils with their higher water holding capacities tend to be slow to drain while sandy soils retain less water and are faster to drain. In reality this rationale would suggest that under normal irrigation practices of say, 1 acre-foot per year, sandy soils will have a higher leaching fraction (loss of water from the root zone) than clay soils. This is not unreasonable; in fact, with most irrigation methods practiced in Saskatchewan this is true.

A second rationale is that sodium problems (dispersion, puddling, crusting) can be enhanced in the presence of certain types of clays. Clays on the Canadian prairies have a predominance of 2:1 crystal lattices (montmorillonites and hydrous micas or illite) and lesser amounts of the 1:1 type crystal structure (kaolinite).

Montmorillonites differ from illites in that they adsorb more cations, disperse more easily, change volume with water content and are more stable than montmorillonites. Illites tend to predominate over montmorillonites in potassium rich soils. Kaolinites are less reactive than illites.

Typical cation exchange capacities for montmorillonite, illite, and kaolinite colloids are 80-100, 15-40, 3-15 meq/100g, respectively. Similar ratings for swelling capacity are high, medium, and low (Buckman and Brady, 1967).

A third rationale is that clays comprise a large portion of the cation exchange surfaces in soils. Their overall net negative charge provides strong attraction for cations. The soil exchange system is in a state of equilibrium with the cations and anions in the soil solution. When irrigation waters introduce high levels of sodium relative to calcium and magnesium, then over time the cations on the exchange system begin to reflect higher sodium levels as a "new" equilibrium is established. As clay content increases time to reach a "new" equilibrium would likely increase. By the same token, if it was found that sodicity problems were arising then it would take even more time to reverse the equilibrium. In fact, the damage may have occurred before any counter-measures could be incorporated.

Thus, the third rationale has several points of concern. One, the more clay the more chance for permeability problems. Two, the more clay, the larger the extent of sodium accumulation. Three, the more clay, the more time required and the greater the difficulty in reversing the situation. Four, clay soils are more difficult to work with than sandy soils and problems on clay soils should be avoided (more caution is warranted).

C. Guidelines For Saskatchewan

In Saskatchewan, the effect of soil texture on irrigation water quality - soil compatibility guidelines must be viewed in two ways. First, there will be a larger accumulation of salt in clay soils than sandy soils because of the inherently lower leaching fraction in clay soils for a given application of water. Second, the chance for sodium permeability problems is higher in clay soils than in sandy soils, particularly in Saskatchewan where illite-montmorillonite 2:1 clay crystal structures dominate. The situation is complicated by the fact that SAR effects of irrigation water on soils can be held in check by increasing the electrolyte or salt content of the soil solution.

Table 9: Salinity and SAR guidelines for irrigation water use in Saskatchewan.

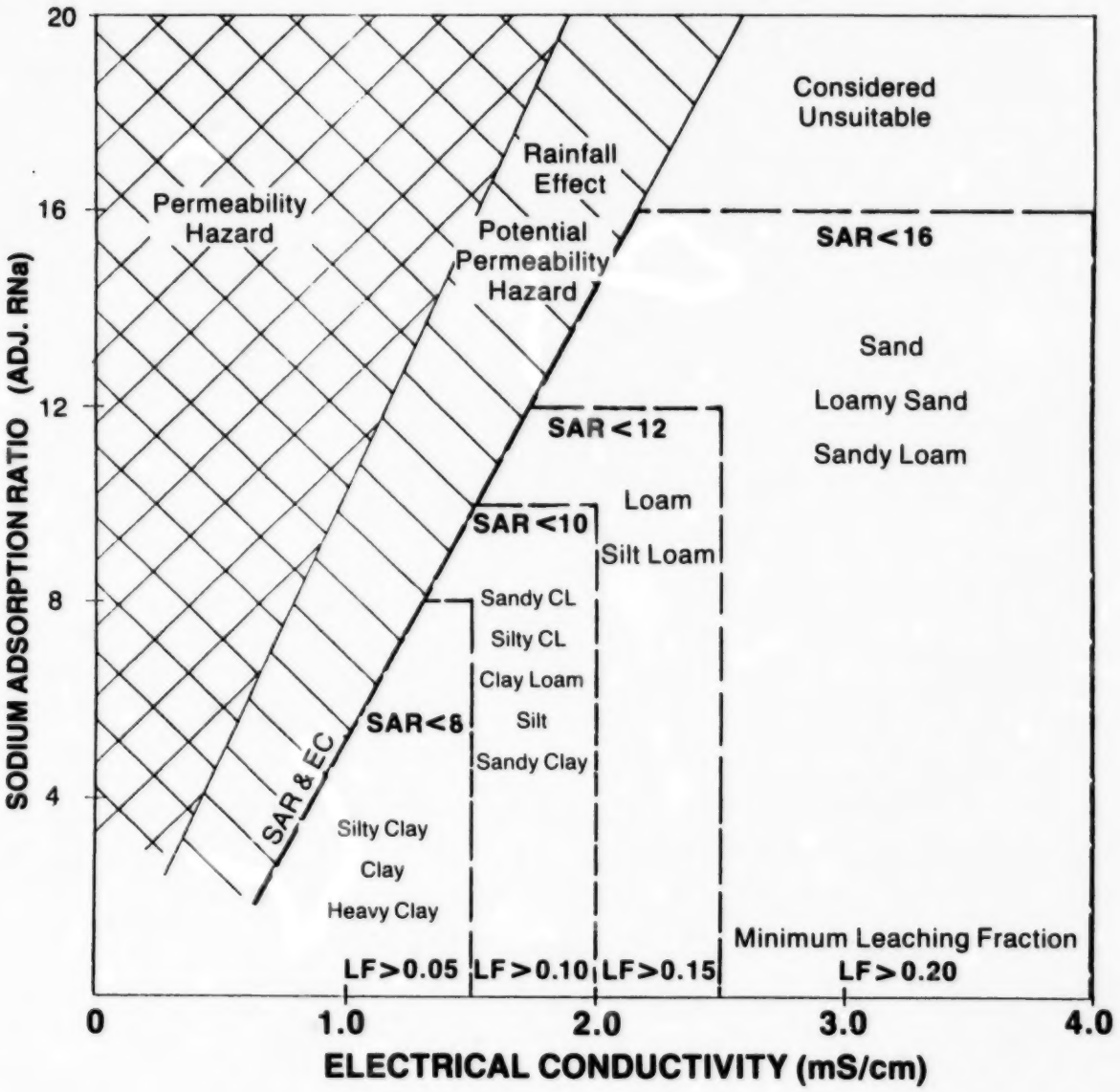
SOIL TEXTURE	MAXIMUM ALLOWABLE SALT CONCENTRATIONS		MAXIMUM ADJUSTED SAR (RNa)	MINIMUM REQUIRED LEACHING FRACTION	APPROXIMATE SALT CONCENTRATION FACTOR
	EC (mS/cm)	mg/ℓ			
Sand Loamy Sand Sandy Loam	4.0	2800	16	0.20	1.0
Loam Silt Loam	2.5	1750	12	0.15	1.16
Sandy Clay Silty Clay Clay Loam Silt Sandy Clay Loam	2.0	1400	10	0.10	1.36
Silty Clay Clay Heavy Clay	1.5	1000	8	0.05	1.78

The proposed salinity and SAR guidelines for Saskatchewan (Table 9) permit a fair degree of leeway for use of saltier waters (up to 2800 mg/ℓ) for irrigation on coarse textured soils, but are fairly restrictive for irrigation of clay soils.

To some extent the guidelines may appear to "promote" irrigation with waters high in salts or sodium but the intent is not meant to do this. Rather the intent is to indicate that on sandy soils where irrigation can be shown to be economically feasible and where water sources for irrigation are of relatively poor quality, irrigation can be achieved without long-term soil degradation. However, at higher salt concentrations the potential for groundwater contamination increases.

The maximum Adj. SAR (RNa) values were set to provide a safety factor. The EC-SAR relationship in Figure 2 is still applicable, but until more knowledge is gained on the rainfall-sodicity-permeability effect for Saskatchewan conditions, it was felt that an interim margin of safety was warranted.

Figure 3: Salinity-SAR Guidelines for Irrigation Water Applied to General Soil Textural Categories in Saskatchewan.



Considerations

1. It is assumed that the soils to be irrigated are well drained for their texture class, and do not have slowly permeable strata or shallow water tables.

2. At higher salt concentrations, salt tolerant crops may have to be grown (see Table 3).

3. The EC-SAR relationship (Figure 2) still applies, but maximum adjusted SAR has been restricted to provide a safety-factor until more knowledge of the EC-SAR relationship in field situations under Saskatchewan conditions is obtained.

4. The SAR calculation of the irrigation water should be adjusted to account for the bicarbonate hazard (after Suarez, 1981) where it is deemed necessary (mainly groundwater). For many surface waters, standard SAR calculations are adequate.

5. Higher salt loading and waters with higher SAR's can be used on sandy soils, but the potential for groundwater contamination should be examined.

6. The salt concentration factor can be used to estimate the average "equilibrium" salt content in the soil profile for each minimum leaching fraction by multiplying by the EC of the irrigation water. This can be related to crop yields.

7. Where source waters exceed 1000 mg/ℓ TDS and SAR's exceed 8 a site-specific soils-hydrology investigation should be made prior to long-term use of such waters for irrigation.

8. The texture of the least permeable soil horizon should be considered to be the "critical" texture for each categorization (also see item 1). Where soil structure and irrigation management permit a higher leaching fraction for a given texture category, then maximum allowable salt levels can be altered accordingly.

9. The above textural categories and associated maximum salt concentrations are approximate and will be modified by management, climate, and soil conditions.

10. Prevailing management practices assure proper leaching fractions.

The adjusted SAR (RNa) calculation proposed by Suarez, (1981) and outlined in Westcot and Ayers (1984) is recommended. However, for most Saskatchewan waters the SAR and Suarez's Adjusted SAR (RNa) appear to be similar (see Table 6). The standard SAR calculation will often be sufficient, unless the quality appears borderline.

The minimum required leaching fraction for each textural grouping provides a target drainage criteria that should be met in order to avoid excessive salt accumulation. In reality, the leaching fraction is the preferred criteria to use, where it is known. For example, if irrigation of a clay loam soil has been such that a minimum leaching fraction of 0.15 has been maintained rather than 0.10, then maximum allowable salt concentrations in the irrigation water can likely be raised to 1750 mg/ℓ TDS with minimal impacts on the soil.

It is recommended in situations where source waters exceed 1000 mg/ℓ or where SAR's exceed 8 that a site-specific soils and shallow hydrogeologic investigation be conducted prior to long-term use of such waters for irrigation. Such a study would examine the drainage component of the area to be irrigated as well as look at potential off-target impacts and contamination of groundwater.

IX. ROLE OF DRAINAGE CRITERIA IN GUIDELINES

A. Definition And Considerations

For soil survey application, the term "drainage" refers to the rate of removal of water from a soil in relation to supply. Since, irrigable areas are generally not subject to natural flooding or inundation for prolonged periods (excluding backflood projects), then for irrigation, the term "drainage" can refer to the rate of water removal through the soil (internal drainage) to the shallow groundwater system and the rate of dissipation of the "new" groundwater mound relative to supply. By definition internal drainage becomes the most important controlling factor for soil water movement, but not at the exclusion of landscape features. Relief, position within the landscape and topography can greatly influence the supply and movement patterns of irrigation water as it moves to the groundwater system.

When assessing an irrigation site, drainage must be considered as a 3-dimensional process. A number of closely related soil and landscape factors like texture, geological uniformity (till, bedrock), intake rates (infiltration), depth to water table, salinity and sodicity, presence of slowly permeable layers, topography, average local relief, presence of depressions, hummocky terrain, potential fringe area impacts, spatial variability of hydraulic conductivity, and soil structure must all be considered. An understanding of local and regional groundwater flow regimes is important. All of this information must be considered and a judgement made that often weights favorable characteristics against those that may be limiting.

In order to simplify the situation, "internal drainage" should perhaps be considered to be synonymous to "leaching fraction". In other words, a well drained area would be synonymous with an area that would provide a good leaching fraction (say greater than 10%) under normal irrigation practices. This would permit the term "drainage" to be associated with a familiar irrigation term which can be quantified, if need be, and at the same time include consideration of a 3-dimensional picture or extent of drainage.

However, the 3-dimensional picture can at times become confusing particularly in complex topography. In the field situation, leaching fractions can vary from location to location. Thus, although the concept of a leaching fraction permits quantification, it may not be practical in the field. The effect of leaching fraction has been largely accounted for in the textural categorization in Table 9. It would not solve the problem to include the leaching fraction one more time as part of the drainage criteria.

The ideal situation would be to have one measurement which could be used as an indicator of "drainability" without having to consider a host of influencing factors. Since it is water and the movement of water through soil to the groundwater that we are dealing with, then one fairly reliable indicator or benchmark as to how well the overall drainage system might perform is the depth to the water table. Ultimately, the local groundwater regime will reflect increased supply of water from irrigation to the groundwater as well as the ability of the system to remove the groundwater away from the area. Under irrigation the local water table levels must be maintained sufficiently deep as

to prevent salinization of the irrigated area, as well as prevent any harmful impact on non-irrigated fringe areas.

The concept of utilizing groundwater as a benchmark for "drainability" is a relatively simple concept and, in most situations, should be effective. It does have the advantage of being relatively quick and easy to measure. Ultimately, local groundwater levels will reflect the drainability of an area.

A major disadvantage of this approach, is that it may be difficult to predict or anticipate the extent and duration of a water table build-up prior to implementation of the irrigation project. A transient water mounding under irrigation is common, but in situations where the applied water that leaches to the groundwater does not all drain away, then a permanent water table build-up will begin to occur. Over time, a new "equilibrium" water table level will be established. Often a permanent water table build-up will not impact on an area. But when water tables are already high, increased water logging and salinization may take place. Hydrogeologic studies may be required to provide an estimate of potential water table problems in critical areas as well as large scale intensively irrigated areas.

Weather conditions and climate can also alter water table levels. An "equilibrium" water table may be somewhat difficult to measure as water table levels generally vary seasonally as well as from year to year. Some degree of field judgement is often warranted in these situations.

B. Depth To Water Table

It is important under irrigated or dryland conditions that the long-term downward water flux (irrigation, rainfall) must exceed the upward water flux (evaporation, evapotranspiration), otherwise water logging and eventual salinization will develop. By definition, a leaching fraction requires a net downward flux of water out of the rooting zone. High water tables limit downward fluxes and promote upward movement of water by capillary action.

Most irrigation guidelines prefer that water tables be below 2 m, but with careful management water tables as high as 1.2 m can be acceptable (Working Group on Irrigation Suitability Classification, 1985). In some situations, installation of a sub-surface drainage system can be utilized to help control the water table level.

In irrigation projects where secondary effluent waters are used, the depth to water table is very important. It determines the thickness of the unsaturated aerated zone in which soil microbial and plant biological activity are greatest and wastewater renovation takes place. Shallow groundwater levels interfere with plant growth and prevent percolation of wastewaters. Without proper control shallow groundwater can promote soil salinization.

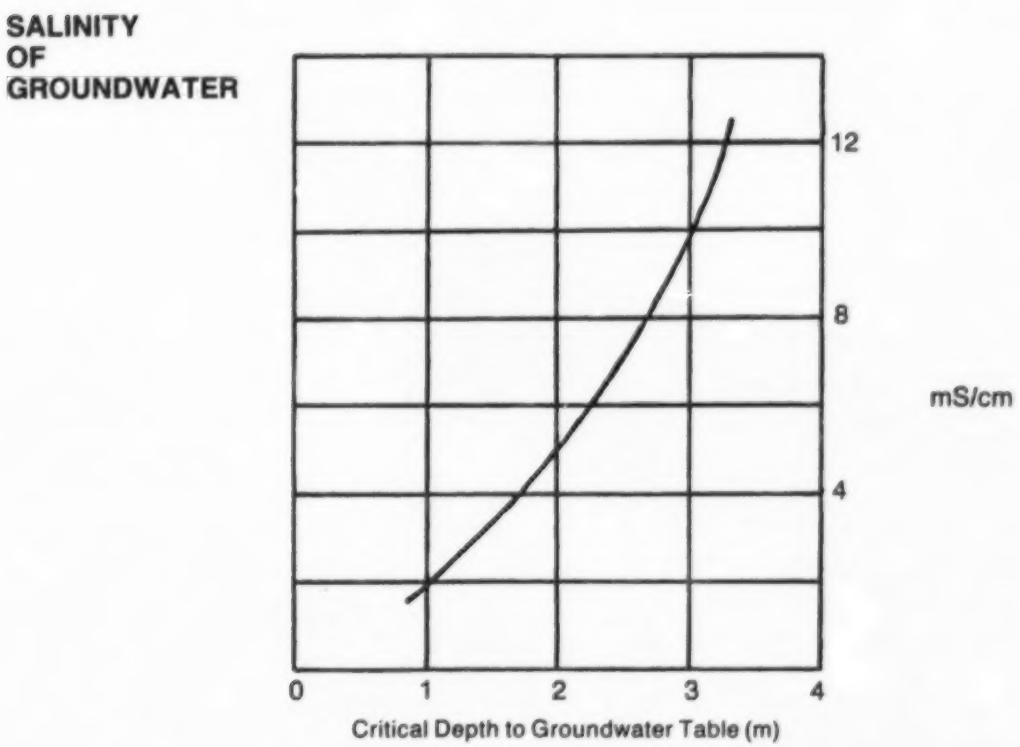
Some recommended depths to water tables for wastewater irrigation projects are summarized in Table 10. With the exception of California, most researchers prefer that land disposal sites for wastewaters have a minimum depth to the water table of at least 1.5 m (5 feet).

For irrigation projects, depth to water table is not as important as maintaining a positive downward flux (i.e a leaching fraction).

Table 10: Some recommended depths to water table for wastewater irrigation.

REFERENCE	RECOMMENDATION
Crites (1984) (California)	0.9 to 1.2 m or more is preferred, otherwise tile drainage required.
Sanks et al (1976) (Montana)	greater than 1.5 m as minimum, 3 m preferred for wastewater renovation.
Saskatchewan Environment (1976)	water table levels should be sufficiently deep to prevent a water table rise to the root zone.
Schmid (1975) (North Dakota)	1.5 - 3.0 m preferred inclusive of allowances for groundwater mounding during irrigation.
US EPA (1973) (general)	greater than 2.4 m to accommodate seasonal fluctuations and prevent groundwater contamination.
Thomas & Harlin (1973) (Pennsylvania)	about 1.5 m

Nevertheless, depth to water table often serves as a reasonable guideline, realizing of course, that some field situations will diverge from the norm. Szalbocs (1982) has developed a relationship between critical depth to water table and salinity of the groundwater. This relationship is shown in the diagram following and may be a useful guideline for equilibrium conditions.



In Saskatchewan it is preferred that water table levels remain at a depth greater than 2 m (6 feet) below ground in order to prevent salinization of the irrigated land. In situations where a net downward flux can be achieved or where artificial drainage has been installed, then shallower water tables may be permissible.

X. SPECIFIC ION TOLERANCES

In addition to the effect of total salinity on water-soil-plant relations, some individual ions can have varying effects on plant growth. The ions considered to be of most concern are boron, chloride, and sodium. Toxicity problems from these ions often accompany and complicate a salinity problem, although toxicity occasionally occurs even when salinity is low.

A. Boron

Boron (B) is one of the essential elements for plant growth but is needed in relatively small amounts. Excess boron is toxic. A boron toxicity problem in irrigation waters is often associated with groundwaters or secondary wastewaters rather than surface streams (Ayers and Westcot, 1976).

A major portion of the plant (B) toxicity criteria for evaluating irrigation waters is based on sand culture work performed in California (Eaton, 1944). Gupta et al (1985) have concluded that there is confusion in the interpretation of Eaton's data as to whether the "B concentration" is that of the irrigation water or the soil solution and also, because of the lack of replication in Eaton's work precision cannot properly be assessed. The authors emphasized the need to establish criteria for evaluating B in irrigation water.

Boron adsorption also plays a role in determining its concentration in the soil solution. Jame et al (1982) have developed a theoretical model to aid in predicting B concentrations in the soil solution.

Despite possible shortcomings of Eaton's data, it has provided reasonable guidelines in the past (U.S. Salinity Laboratory Staff, 1954; Wilcox, 1960; Allison, 1964; Bingham, 1973; NAS/NAE, 1973; Bernstein, 1974; Hart, 1974) which have been extensively utilized in the last decade (Ayers and Westcot, 1976; U.S. EPA, 1976; Ayers, 1977; Shainberg and Oster, 1978; Westcot and Ayers, 1984; Environment Canada, 1984; and Maas, 1985 in press). Using data taken from Maas (1985, in press), the relative boron tolerance of agricultural crops has been tabulated (Table 11, from Westcot and Ayers, 1984).

The results compiled in Table 11 show that most fruit trees, small fruits, and berries are sensitive to B concentrations exceeding 1.0 mg/ℓ. Wheat and barley and field crops such as sunflowers and potatoes are categorized as sensitive, although field crops such as oats, corn, tobacco, mustard, sorghum, and sugar beets are tolerant (irrigation water concentrations ranging from 2.0 to 6.0 mg/ℓ). Vegetable crops vary in their tolerance: onions and beans are sensitive; peas, carrots, cucumbers, lettuce, and celery are moderately affected; and tomatoes, parsley, beets, and asparagus are tolerant.

In Saskatchewan, it is recommended that irrigation waters having B concentrations less than 1.0 mg/ℓ be considered acceptable for irrigation of most crops. Sensitive berries and fruits can be affected by this concentration.

In situations, where B concentrations exceed 1 mg/ℓ, the long-term use of the land resource should be considered. As an example, if the area is to be utilized for alfalfa production, then higher boron concentrations can be tolerated. If at some later period it is decided that wheat production was more profitable then yield reductions may be experienced.

Table 11: Relative boron tolerance of agricultural crops (from Westcot and Ayers, 1984)

TOLERANCE	B (Mg/ℓ) SOIL-WATER	AGRICULTURAL CROPS
Very Sensitive	< 0.5	lemon, blackberry
Sensitive	0.5 - 1.0	avocado, grapefruit, orange, peach, cherry, plum, fig, grape, walnut, pecan, cowpea, onion, garlic, sweet potato, wheat, barley, sunflower, mung bean, sesame, lupine, strawberry, Jerusalem artichoke, kidney bean, lima bean, peanut
Moderately Sensitive	1.0 - 2.0	red pepper, pea, carrot, radish, potato, cucumber
Moderately Tolerant	2.0 - 4.0	lettuce, cabbage, celery, turnip, Kentucky bluegrass, oats, corn, artichoke, tobacco, mustard, clover, squash, muskmelon
Tolerant	4.0 - 6.0	sorghum, tomato, alfalfa, purple vetch, parsley, red beet, sugar beet.
Very Tolerant	6.0 - 15.0	cotton, asparagus

1. Assumptions used to derive Table 11 were:

   (a) Boron concentrations are maximum concentrations tolerated in water without yield or vegetative growth reductions.

   (b) Boron tolerances will vary depending upon climate, soil conditions and crop varieties, i.e. the table is only a guideline.

   (c) Maximum concentrations tolerated in the applied irrigation water are approximately equal to soil-water values or slightly less (also see conclusions of Gupta et al (1985) concerning this assumption).

B. Chloride

Chloride (Cℓ) is essential to the growth of plants; however, most woody plant species (stone fruits, citrus, avocados) are sensitive to low concentrations of chloride while most vegetable, grain, forage and fibre crops are not (Chapman, 1966; Oster and Rhoades, 1984).

Chloride damages can occur in two ways. First, the Cℓ ion can be taken up by the roots and moved upward to accumulate in the leaves, similar to sodium. Excessive accumulation causes leaf burn, chlorosis, and twig die-back. Second, direct foliar absorption of chlorides from sprinkler irrigation can also cause damage, particularly on hot, windy days (Bernstein, 1965).

The degree of tolerance to chloride ions is summarized in Tables 12 and 13 for root uptake and foliar injury from sprinkler absorption, respectively (data taken from Maas, 1985, in press as summarized by Westcot and Ayers, 1984). Stone fruits such as apricots, cherries, peaches, and plums; and some berry plants including strawberries, raspberries, boysenberries, and blackberries may be sensitive to concentrations of chlorides in irrigation waters ranging from 110 to 250 mg/ℓ. Often the overall salinity tolerance of the crop (see Table 3) will be exceeded and cause yield reduction prior to chloride ion toxicity.

Foliar damage by sprinkler irrigation due to excessive absorption of chloride or sodium directly by the leaves is most likely to occur on fruit trees as they are most sensitive, but grapes, peppers, potatoes, and tomatoes are also sensitive.

Generally, the effects of leaf burning can be minimized by night-time sprinkling and water applied at a rapid continuous rate.

For most irrigated crops in Saskatchewan chloride levels in the irrigation water are not a concern except for their contribution to salinity.

Table 12: Chloride tolerance of fruits and woody crops by root uptake (From Westcot and Ayers, 1984)

ROOTSTOCKS	Cℓ (mg/ℓ) IN IRRIGATION WATER*	CULTIVARS	IRRIGATION WATER
Avocado	110-180	boysenberry	250
		blackberry	
		raspberry	
Citrus-			
grapefruit	600		
rough lemons	355		
sweet oranges	250		
Grapes	710 - 960	grapes	230 - 460
Stone Fruit (peaches, plums, etc.)	180 - 600	strawberry	110 - 180

*Threshold values at which stress is first noted

Table 13: Sodium or chloride concentrations in irrigation water causing foliar damage. (From Westcot and Ayers, 1984)

	SENSITIVE	MODERATELY SENSITIVE	MODERATELY TOLERANT	TOLERANT
Na or Cℓ (meq/ℓ)	< 5	5-10	10-20	> 20
Cℓ (mg/ℓ)	< 178	178-355	355-710	> 710
Na (mg/ℓ)	< 115	115-230	230-460	> 460
	almond	grape	alfalfa	cauliflower
	apricot	pepper	barley	cotton
	citrus	potato	corn	sugarbeet
	plum	tomato	cucumber	sunflower
				safflower
				sesame
				sorghum

C. Sodium

Sodium (Na) can affect plants through five avenues:

(a) direct root uptake and plant accumulation of toxic levels;

(b) direct foliar absorption from sprinklers (discussed for chloride, see Table 13);

(c) nutritional imbalance due to excessive concentrations of sodium preventing the uptake of the necessary Ca + Mg;

(d) deterioration of soil physical conditions (discussed in section VI of this report); and

(e) sodium is a major cation contributing to osmotic stress, part of the salinity effect on plants.

It is often difficult to separate the various direct and indirect toxic effects of sodium and usually these are coupled with an overall osmotic or "salinity" effect. However, some plants (fruits, avocados, beans) are sodium sensitive and can be affected at low exchangeable sodium percentages. A broad grouping of crop tolerances to sodium is presented in Table 14 (from Hart, 1974). As a rule of thumb, soil structure is usually damaged before SARs are high enough to cause nutritional problems.

Sodium absorption ratio (SAR) and exchangeable sodium percentage (ESP) are often used interchangeably to express tolerance levels to sodium toxicity. The reason is that sodium toxicity is often modified and reduced if calcium is present. Moderate amounts of calcium may prevent it. Thus, a reasonable evaluation of the potential toxicity is possible using SAR, i.e. SAR is actually a better indication of nutrient imbalance.

Table 14: Tolerance of crops to sodium (From Hart, 1974)

TOLERANCE	SAR OF IRRIGATION WATER	CROP	CONDITIONS
Very Sensitive	2 - 8	deciduous fruits, avocado, nuts	leaf tip burn, leaf scorch
Sensitive	8 - 18	beans	stunted growth
Moderately Tolerant	18 - 46	clover, oats, tall fescue	stunted due to nutrition and soil structure
Tolerant	46 - 102	wheat, cotton, lucerne, barley, tomatoes, beets, tall wheatgrass, crested wheatgrass	stunted due to soil structure

Sodium sensitive crops include deciduous fruits, nuts, citrus, avocado, and beans. In recent guidelines, Westcot and Ayers (1984) have categorized the sodium effects as follows:

Guidelines For Sodium Sensitive Crops

SAR of Irrigation Water	Restriction on Use
< 3	none
3 - 9	slight to moderate
> 9	severe

For most annual crops which are not as sensitive, they suggest that the salt tolerance tables (Table 3) be used as a guide.

In summary, sodium and chloride toxicity have been mainly observed in the fruit tree industry. For most vegetable, grain, forage and fibre crops, sodium and chloride levels in the irrigation water are not a concern, except for their contribution to salinity. In Saskatchewan, the salinity and SAR guidelines should provide adequate protection from excess sodium.

XI. OTHER ELEMENTS AND PESTICIDES

A. Metals

As a general rule, heavy metals are rarely a problem in effluents. A large proportion of the metals in raw wastewater settle out with the sludge. However, effluent from heavily industrialized areas may contain elevated levels of trace metals (Environment Canada, 1984).

Two sets of guidelines for trace metals are presented in Table 15. One set is for continuous use and the other for use up to 20 years on fine-textured soils of pH 6.0 to 8.5. The criteria for maximum concentrations for continuous use is based on an application of 4 acre-feet per year and thus should afford ample protection for Saskatchewan irrigation where one acre-foot is usually applied. According to Page and Chang (1984) a typical wastewater can be applied for almost 100 years before any trace-element accumulation in the soil may reach a currently proposed upper limit for trace-element soil deposition.

None of the elements listed in Table 15 cause toxicities at the levels given, and the water should be considered safe for continuous irrigation of all crops on all soil types when these values are not exceeded. This does not mean that if the suggested limit is exceeded that phytotoxicity will occur. Most of the elements listed are readily fixed or tied up in soil and accumulate with time. Repeated applications in excess of the level suggested would eventually increase the soil concentration to a level where phytotoxicity might occur. The intent of the suggested limits is to ensure that the land where effluent irrigation water is used, soil and product quality for all potential crops is not impaired.

It is recommended that the values in Table 15 be considered the maximum long-term average concentrations based upon normal irrigation applications. If it may be necessary over the short-term to exceed either the maximum concentration or the normal water application rate than an adjustment in future concentration or water application rate needs to be made.

(a) These levels will normally not adversely affect plants or soils. No data is available for mercury, silver, tin, titanium, tungsten.

(b) Recommended maximum concentration for irrigating citrus is 0.75 mg/ℓ.

(c) Only for fine-textured acid soils or acid soils with relatively high iron oxide content.

1. References for this table include (NAS/NAE, 1974; Environment Canada, 1984; and Westcot and Ayers, 1984; Canadian Water Quality Guidelines, 1987).

B. Nutrients

The major nutrients required by crops are nitrogen (N), phosphorus (P), and potassium (K). Crop removal of nutrients varies depending upon crop type, yield and the amount of plant material harvested. N, P, and K removed from soil by harvesting must be replaced if soil productivity is to be maintained.

Table 15: Recommended maximum concentrations of trace metals in irrigation water.

ELEMENT	FOR WATERS USED CONTINUALLY ON ALL SOIL (mg/ℓ)	FOR USE UP TO 20 YRS. ON FINE-TEXTURED SOILS OF pH 6.0 TO 8.5 (mg/ℓ)	REMARKS
Aℓ	5.0	20.0	productivity reduction in acid soils
As	0.10	2.0	plant toxicity varies, rice very sensitive
Be	0.10	0.50	plant toxicity varies
Cd	0.010	---	plant accumulation, human food chain
CO	0.050	5.0	tomatoes sensitive, precipitates at pH>7
Cr	0.10	---	lack of knowledge on toxicity, conservative limits
Cu	0.20	5.0	toxic to plants
F	1.0	15.0	inactivated by neutral and alkaline soils
Fe	5.0	20.0	can immobilize P and Mo in soils
Li	2.5b	---	generally tolerated, mobile, similar to B
Mn	0.20	10.0	toxic in acid soils
Mo	0.010	0.050c	toxic to livestock eating forage
Ni	0.20	2.0	generally toxic to plants, less so in pH>7 soils
Se	0.020	---	toxic to both plants and animals
Sn	---	---	tolerance unknown, plants don't accumulate
Ti	---	---	same as above
W	---	---	same as above
V	0.1	1.0	toxic to plants
Zn	1.0 (soil pH < 6.5) 5.0 (soil pH > 6.5)	---	toxic to many plants, reduced toxicity at pH>6.0

(a) These levels will normally not adversely affect plants or soils. No data are available for mercury, silver, tin, titanium, tungsten.

(b) Recommended maximum concentration for irrigating citrus is 0.75 mg/ℓ.

(c) Only for fine-textured acid soils or acid soils with relatively high iron oxide contents.

1. References for this table include NAS/NAE, 1974; Environment Canada, 1984; Westcot and Ayers, 1984; and Canadian Water Quality Guidelines, 1987.

Most surface irrigation waters and groundwaters do not contain appreciable nutrients. However, most secondary effluent waters are enriched with nutrients and for this reason some guidelines or criteria may be required. Sewage effluent in particular tends to be nutrient enriched and can help supply crop fertilizer needs (Pound and Crites, 1975; Bole and Bell, 1978; and Jame et al, 1984).

In certain instances nutrients can be in excess of plant needs and cause problems related to excessive vegetative growth, delayed and uneven maturity, or reduced quality. The most beneficial and the nutrient most often in excess is nitrogen.

The total nitrogen content of municipal wastewater following secondary treatment ranges from 5 to 30 mg/ℓ, but the nitrogen concentration as well as the form of nitrogen (NH[4]-N, NO[3]-N, organic-N) depends on the degree and type of treatment that is given (Environment Canada, 1984). In terms of total N, each 10 cm application of irrigation water could supply about 5 to 30 kg/ha of nitrogen. As a general rule about 50 - 60% of the nitrogen will usually be in the ammonium form, a small amount in the nitrate form and the remainder as organic nitrogen. In this situation, the application of 30 - 40 cm of irrigation water will generally not supply more nitrogen than the crop can use.

For Saskatchewan it is recommended that nitrogen loadings from irrigation water (primarily wastewater) should not exceed the nitrogen requirement of the crop to be grown. Over abundances of N can cause excessive vegetative growth

and crop lodging. Excess nitrates in forage crops may be toxic. Nitrate may be converted to nitrite which, following ingestion, may cause nitrate poisoning (methemoglobinemia or cyanosis).

Phosphorus in effluent from secondary treatment systems varies from 2 to 10 mg/L (4-20 mg/ℓ P205) unless removal has been accomplished during treatment. Excess phosphorus is not considered to be toxic to plants but may induce deficiencies of calcium, zinc, iron, and manganese. These trace element deficiencies can be corrected by the addition of chemical fertilizers. Phosphorus in effluent can build up the soil phosphorus and reduce the need in future years for supplemental phosphorus fertilizers.

Excessive phosphorus has not been a problem and no guideline value is given for its evaluation, but checks of the reclaimed wastewater should be made in conjunction with soil testing for fertilization planning.

Most Saskatchewan soils are adequately supplied with potassium. Potassium is generally non-toxic to plants or plant consumers. It is generally present at low or moderate concentrations (10-30 mg/ℓ) in treated wastewaters and therefore should not cause toxicity problems although nutrient imbalance may occur. No guidelines have been set for potassium.

C. Pesticides

Insecticides, herbicides and fungicides comprise the major agricultural pesticides. Pesticides have both beneficial and detrimental characteristics and may be regarded as environmental contaminants if they extend beyond the area of intended application or persist longer than is necessary to control the pest. A major concern with pesticides is their accumulation in the environment and their biological accrual in the food chain.

Pesticides may reach the aquatic environment in a number of ways: (i) drift from aerial spraying; (ii) surface runoff; (iii) percolation and subsurface runoff from treated lands; (iv) careless application or spillage; (v) direct aquatic application to control undesirable aquatic organisms; (vi) sewage discharge; and (vii) industrial effluents. Pesticides may also be subject to atmospheric transport and redeposition (McNeely et al, 1979).

Pesticides vary in their persistence in the environment. The chlorinated hydrocarbons are the most persistent (DDT, dieldrin, chlordane, heptahlor, aldrin). Organophosphate and carbamate pesticides are known to be more readily hydrolyzed and are less persistent. The phenoxyacid herbicide 2,4-D is in wide use. When used along the banks of irrigation canals there is the possibility of contamination of the irrigation water. These materials are known to be subject to rapid degradation in soils but probably persist for longer periods in irrigation and runoff waters (Hart, 1974).

There is little evidence that under normal use insecticide contamination of irrigation water would be detrimental to plant growth or accumulate in or on plants in toxic concentrations (Hart, 1974). Herbicides on the other hand could be harmful to crop growth if misused. Since most natural waters used for irrigation are also used for other purposes, the pesticide criteria for other water uses will adequately protect irrigation agriculture.

Insecticide residues in irrigation waters are variable depending upon land and crop management practices. There have been no documented toxic effects on crops irrigated with waters containing insecticide residues (NAS/NAE, 1974).

In contrast to insecticides, misuse of herbicides can present a greater hazard to crop growth. Herbicides are likely to be found in irrigation water under the following circumstances:

(1) during their purposeful introduction into irrigation water to control submerged weeds; and

(2) incidental to herbicide treatment for control of weeds on banks of irrigation canals.

The tolerances of a number of crops to various herbicides used in and around water are usually much higher than concentrations found in water following normal use of the herbicides. Aromatic solvent (xylene) and acrolein have been widely used in Western United States for keeping irrigation canals free of submerged weeds and algae and are not harmful to crops at concentrations needed for weed control (NAS/NAE, 1974).

In Saskatchewan the use of pesticides for controlling submerged weeds/algae in irrigation canals requires a permit from Saskatchewan Environment and Public Safety. Guidelines for the application of such pesticides have been developed to aid in the regulation of this activity. Only the uses registered for a pesticide by Agriculture Canada are allowed by federal regulation. Xylene is not registered in Canada for aquatic nuisance control.

Irrigation farming trends for the future would suggest that there will be increased use of sprinkler irrigation systems to apply fertilizers (fertigation) and herbicides (herbigation). In these situations it is recommended that the herbicides be applied as prescribed by the manufacturer.

Where concerns may arise on acceptable pesticide limits or where there may be environmental health considerations, it is recommended that advice be sought from Saskatchewan Environment and Public Safety.

D. Biological Organisms

Many microorganisms that are pathogenic to animals may be carried in irrigation waters, particularly surface waters. A large variety of bacteria may be discharged into irrigation water in municipal and industrial wastes including those from food processing plants, slaughter houses, poultry processing operations, and feedlots. The diseases associated with such bacteria include bacillary and amoebic dysentery, Salmonella gastroenteritis, typhoid and paratyphoid fevers, leptospirosis, vibriosis and infectious hepatitis. Studies have emphasized the value of fecal coliform density as a indicator of the occurrence of Salmonella, the most common bacterial pathogen in irrigation water (NAS/NAE, 1973).

Pathogens that pose potential hazards to human and animal health enter municipal sewage from a variety of sources. Humans infected with enteric diseases are a major source. Others are effluents from abattoirs, rendering plants and dairies, and animal feces that have been deposited on yards or streets and carried into the sewage system via surface water drainage. Sewage treatment practices reduce the number of pathogenic organisms but evidence is abundant that detectable amounts of most types can occur in treated wastewaters and sludges. Pathogenic organisms are classified as bacteria, viruses, helminths and protozoa (Table 16).

Table 16: Brief summary of some organisms of health concern in sewage.

BACTERIA	REMARKS
Salmonella	most common; causes gastroenteritis; usually spread by eating contaminated meat; no reported diseases from irrigation with secondary effluent, but reported outbreaks with raw sewage.
Escherichia Coli	normally present, causes diarrhea in children and gastroenteritis and urinary infections in adults; not expected to be a problem in treated wastewater.
Mycobacteria	tuberculosis, skin ulcers and leprosy; bacilli must be ingested; resists disinfection and persists for months; little evidence of infection from land application.
VIRUSES	generally host-specific and cannot replicate outside most cells; tend to concentrate in sludge; little evidence to indicate a health hazard in effluent or other irrigation waters.
HELMINTHS	
Nematodes (Roundworms) (ascaris lumbricoides)	parasitic intestinal worms; eggs are biologically resistant; reported to survive for up to 7 years in soil; important in sludge (not effluent).
Cestodes (Tapeworms) Taenia saginata (beef) T. Solium (pork)	usually associated with ingestion of improperly cooked affected meat; usually associated with sludge and would require direct ingestion; not considered an irrigation problem.
PROTOZOA	enteropathogen protozoa cysts are resistant to disinfectant and environment stress; associated with sludge; direct ingestion required.

The major routes of potential exposure to pathogens in irrigation water are contact, inhalation of aerosols, consumption of water from a contaminated aquifer and consumption of portions of plants or animals which have been contaminated by irrigation water. An excellent review of the historical outbreaks from such contamination has been published (Parson et al, 1975) and indicates that most were associated with gross contamination with fecal material or raw sewage.

Where spray irrigation is employed the formation of aerosols and transport by wind is a primary health concern. Normally, spraying should not take place during high winds. Solar radiation and dessication of aerosol droplets are effective in deactivating most pathogens under ideal conditions, but the use of land buffer zones to separate irrigation areas from inhabited areas is considered prudent. Spray irrigation can diminish levels of bacteria in treated effluent (Biederbeck, 1979), but little is known about the effects on viruses, cysts and ova.

Once on the soil, most enteric organisms are eventually deactivated by natural environmental stresses. Relatively few of these microorganisms (only bacteria and fungi) are able to proliferate in soil. The majority are affected by ultraviolet light, predation, desiccation and adverse temperatures in such a way that they are no longer recoverable by normal microbiological techniques (Bell and Bole, 1976; Biederbeck, 1982).

Fecal coliforms are considered more reliable as an indicator of effluent quality than total coliforms because of their greater specificity for fecal pollution. However, fecal coliforms cannot always be considered a reliable indicator of the presence of viruses, cysts, or ova because of the greater sensitivity of fecal coliforms to chlorination and other environmental stresses than the latter

pathogens. Thus, high levels of fecal coliforms (and other bacterial indicators such as fecal streptococci) can be taken as presumptive evidence of the presence of pathogens; however, absence cannot be used to infer the absence of pathogens.

At Lethbridge, Bell (1976) concluded that fecal coliforms on alfalfa plants irrigated with sewage lagoon effluent were completely destroyed by exposure to 10 hours of bright sunlight. No decrease in numbers was observed under cool, damp, overcast conditions. In a similar study dealing with reed canary grass (Bell and Bole, 1976), exposure to 50 hours of sunlight under semiarid prairie conditions was sufficient to destroy virtually all fecal coliforms present on the grass, after irrigation with sewage effluent containing about 3.2 x 10 (4) fecal coliforms/100 m/ℓ. This was considerably longer than the 10 hours previously shown for alfalfa. The difference between species is due to the presence of leaf sheaths on the grass in which effluent could collect and be protected from the bacteriocidal effects of bright sunlight.

Biederbeck (1980, 1982), indicated that fecal coliforms on grain crops can be effectively eliminated in the absence of bright sunlight as long as the weather is dry and warm. The following guideline was provided:

"To ensure complete elimination of fecal coliforms, effluent irrigated small grains and oilseeds should be exposed to a minimum of 10 hours of bright sunlight or 2 days of overcast but dry weather between the end of irrigation and the start of harvest."

As the water requirements of cereals greatly decrease during ripening, irrigation is not necessary close to harvest and the recommended decontamination conditions are easily met. Thus, small grains and oilseeds can be produced safely under spray irrigation with treated municipal wastewater.

Experiments indicated that corn is definitely unsuitable for wastewater irrigation by sprinkler (Biederbeck, 1980). Extensive survival and rapid growth of fecal coliforms within the husks and leaf sheaths pose serious health hazards. To avoid health risks wastewater irrigation systems for corn must employ gravity flow rather than spray systems (Biederbeck, 1982).

Although most surface waters used for irrigation have been assumed to be relatively free of microbial pathogens, wastewaters are not. As an indicator for the presence of other pathogens, the number of fecal coliforms present is often used as a guide.

In Saskatchewan, general guidelines for environmental health protection have been outlined in Saskatchewan Environment and Public Safety booklets on "Water Quality Objectives" (1983) and "Sewage Effluent Irrigation Guidelines" (1983). The approach used is to examine each case of waste disposal and water pollution on its own merits considering each case from a broader water quality management point of view. This is accomplished by regulating the construction/operation of effluent irrigation projects through the Saskatchewan Water Corporation and Saskatchewan Environment and Public Safety. Saskatchewan Environment and Public Safety handles the environmental acceptability of effluent irrigation by providing comments to Saskatchewan Water Corporation on the project proposal and by issuing permits for the disposal of effluent subject to detailed monitoring and reporting conditions.

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